A Neurophilosophical Thesis About Consciousness

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In this paper we propose that consciousness is a prediction tool that places the organism's experiences into a four-dimensional description of the universe. While doing so, consciousness uses knowledge derived from our ancestors, which is coded into our DNA, as well as knowledge that we gained from the community in which we live. We call this type of consciousness collective consciousness, which transitions to individual consciousness during adolescence. Neural oscillations form the best candidates for understanding the neural substrates of these two types of consciousness: slow oscillations (delta–theta) represent collective consciousness, while fast oscillations (gamma) represent individual consciousness. Finally, we suggest that there are four developmental stages of consciousness, which parallel neurodevelopment of the brain: primitive, proto, immature, and mature consciousness.

Keywords: consciousness, neural mechanisms, brain oscillations

Organisms have developed various mechanisms to survive the continuously changing conditions of the environment, and those species that do not have suitable survival mechanisms have vanished. The development of consciousness[1] in this sense must have coincided with the survival of many species and was a further step in the evolution of new species. According to evolutionary cognitive

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[1] Throughout the paper, we will use "consciousness" as a state of mind in which there is knowledge of one's own experience and of the existence of one's surroundings, as described by Damasio (2010).

neuroscience, consciousness "emerged" in order to enhance the chances of survival and the likelihood that the organism would pass on its genes (for a review see Wallace, 2012). As the volume and complexity of information coming into the brain increased and as the organism developed increasing capacity for multiple behaviors, responding in a stereotyped manner became difficult. Increasing sensory capabilities and motor skills were rewarded with survival. Multimodal association areas, initially developed for processing incoming sensory information, blossomed and began to provide the organism with an awareness of self and environment. Advancements in memory storage and retrieval provided the organism with a sense of continuity through time. Consciousness emerged through this process and parallel to the evolutionary development of the human brain (for reviews see Krill, Platek, Goetz, and Schackelford, 2007; Oro, 2004).

Several neuroscientific hypotheses of consciousness have been suggested. Damasio (1994) argues that the mind is a set of representations or neural configurations that becomes images and that can be manipulated to become forms of higher consciousness. Edelman (2003) considers cyclic processing, which he describes as the re-entrance of neural activity in the same region after circulating in so-called re-entrant (or feedback) circuits, to be crucial for the constitution of consciousness. His theory of neural group selection is based on the ability of cortical neuron groups to select certain response patterns, which constitute cerebral maps, in reaction to a given stimulus. According to parallel-distributed processing theory (McClelland, Rumelhart and the PDP Research Group, 1986; Rumelhart, McClelland, and the PDP Research Group, 1986), consciousness is composed of several relatively independent and specialized systems that operate in parallel. The information processed by the mind is transformed and then stored in associative networks. Neural synchronization (Buzsaki and Draguhn, 2004; Crick and Koch, 2003), global workspace (Baars, 2005; Dehaene and Changeux, 2011; Dehaene, Changeux, Naccsacke, Sackur, and Sergent, 2006), and information integration (Seth, Barrett, and Barnett, 2011; Tononi, 2004; Tononi and Koch, 2008) theories are alternative ways for understanding the neural correlates of consciousness.

In this paper, we aim to take further the previous views about consciousness. We will propose that consciousness can be divided into different subgroups, and we will explain the development of these subgroups according to two different classifications. Accordingly, consciousness can be grouped with respect to its content and phylogenetic development: collective and individual consciousness. An additional classification can be made according to neurodevelopment: proto consciousness, primitive consciousness, immature consciousness, and mature consciousness. Consciousness is a prediction tool that compares the information that comes from external stimuli with already existing mental information, which has four dimensions: the knowledge about the self, objects, time, and space. If these two sources of information are in conflict, then consciousness gives a prediction error, and the new information must be revised to be accepted. Thus,

consciousness is an information processor that places the organism's experiences into the four-dimensional description. We propose that synchronization of the neural oscillations is necessary to integrate new information that comes from external stimuli with already existing knowledge in consciousness. Accordingly, slow wave oscillations such as delta and theta are more active in more primitive and earlier forms of consciousness (such as collective consciousness), while fast wave oscillations such as gamma, dominate in more mature forms of consciousness (such as individual consciousness).

Consciousness as a Prediction Tool

Consciousness is a part of the decision-making process, and by creating a hypothesis about the results of action/inaction of the organism, consciousness helps to find the best solution for gaining the maximum benefit. We need information to make a decision. The main sources of this are the coded information in our DNA and the information gathered by our life experience (beginning in intrauterine life). Examples of the information coded in our DNA are primitive reflexes, raw affective states (i.e., hunger) and the behavior behind these states (i.e., seeking food). Information gathered by our life experience can be both conscious and unconscious. Thus, decision making is not necessarily conscious. In fact, many day-to-day decisions are unconscious or implicit.

In many situations, a decision must be made quickly. Thus, organisms need predictions, which are created by former experiences and whose validity has been tested. These predictions are in our collective memory created by our ancestors' survival experience. Predictions can be short-cuts that increase functionality for adaptation and to ensure the efficient use of energy. According to the predictive processing framework, the brain is continuously attempting to minimize the discrepancy between incoming sensory inputs and its own emerging models of the causal structure of the world (Clark, 2013; Friston, 2010; Rao and Balland, 1999). Conscious content arises when top–down expectations or predictions are verified by matching the sensory input (minimizing the prediction error) [Pinto, van-Gaal, de Lange, Lamme, and Seth, 2015]. When we see a snowman on the beach in summer, the information that "this cannot be real" enters our consciousness to minimize the prediction error. The predictive processing framework suggests that probability-density distributions that are induced by hierarchical generative models are our basic means of representing the world and that prediction-error minimization is the driving force behind learning, action-selection, recognition, and inference (Clark, 2013).

Thus, consciousness can be seen as a prediction tool that compares incoming sensory stimuli with already existing knowledge about the structure of the world. However, the question is the following: From where does this "already existing knowledge" derive? We contend this knowledge derives from the

information in the DNA (collective consciousness, which we will discuss below) and from the organism's former experiences, which has a minimal prediction error. This information has four dimensions: (1) knowledge about the self, (2) knowledge about objects, (3) knowledge about space, and (4) knowledge about time.

Knowledge about the Self

What distinguishes human beings from other living organisms is that a human perceives herself as a "Self." Previously, we have proposed that the self is developed hierarchically in a multi-layered process, which is based on the evolutionary maturation of the nervous system and patterns according to the rules and demands of the external world (Ceylan, Dönmez, and Ünsalver, 2015).

The most primitive self, which we have called the "subjective self," exists during the earliest stage of development and includes homeostatic and autonomic reactions connected to affective states as well as to the primordial feelings and drives of the infant. There is no differentiation between the self and objects at this stage, and all objects are considered to be a part of the subjective self. The regions that are referred to as the "default mode network" and that are active when individuals are at rest (lying down quietly, engaged in self-reflective thought) have been related to the self (Buckner, Andrews–Hanna, and Schacter, 2008; Fransson and Marrelec, 2008). The default mode network has also been related to mental time travel, which is the capacity to mentally relieve past events and imagine possible future ones, which is a significant component of sense of self (Corballis, 2015).

Knowledge about these different stages of the self develops as we begin to connect with the outer world. Sensory input about the self comes from peripheral sense organs such as mechanoreceptors and proprioceptive receptors as well as from the inputs from the inner body through autonomic homeostatic mechanisms and autonomic systems. These inputs interact with the knowledge about being a reflective self, which is coded in the cortex, and taken together, they form the "knowledge of self."

In his sensorimotor explanation of consciousness, Humphrey (2006) states that sensations derive their characteristic phenomenology from the fact that they are — in evolutionary origin — a kind of bodily action, involving reaching back to the stimulus at the body surface with an evaluative response. According to this view, consciousness has become private — necessarily private — on the phenomenal level: one person cannot in principle have access to another person's subjective awareness of what it is like to be conscious, to be sensing red, for example. But then consciousness has also become private — contingently private — on the propositional level: meaning that one person usually does not have access even to the objective fact that another person is sensing red (Humphrey, 2007).

Knowledge about Objects

Knowledge about objects is stored as neural networks in the neocortex. Each network carries the different dimensions of a particular object and all are activated together when we see a particular object. This emplacement process of forming one particular object by using different dimensions is called cognitive processing. Cognitive processing includes the recognition of an object by means of a mechanism that is established by consciousness.

Functional neuroimaging studies have revealed dissociations in the recognition of different object categories, such as faces, natural objects, and manufactured objects (Joseph, 2001). Face recognition activates inferior areas of the ventral temporal cortex (Chao, Haxby, and Martin, 1999; Gauthier, Tarr, Anderson, Skudlarski, and Gore, 1999; Haxby, Ungerleider, Clark, Schouten, Hoffman, and Martin, 1999; Ishai, Ungerleider, Martin, and Haxby, 2000; Kanwisher, McDermott, and Chun, 1997), while manufactured objects activate more medial aspects of the fusiform gyrus (Chao et al., 1999; Haxby et al., 1999; Ishai et al., 2000), and natural objects activate more widely distributed areas in the occipital and ventral temporal cortex (Chao et al., 1999; Damasio, Grabowski, Tranel, Hichwa, and Damasio, 1996; Martin, Wiggs, Ungerleider, and Haxby, 1996; Moore and Price, 1999; Smith et al., 2001).

For the interpretation of object stimuli, cognitive knowledge in the form of semantic knowledge and task information feeds back to the inferotemporal cortex from the perirhinal and prefrontal cortex, respectively (Lehky and Taraka, 2016). We use words to describe objects, and linguistic typology can provide cognitive neuroscientists with important knowledge about the representations of these words in the brain (Kemmerer, 2014). Prototypical nouns involve references to objects, and their meanings rely primarily on the ventral temporal lobes, which represent the shape features of the entities (Damasio, Tranel, Grabowski, Adolphs, and Damasio, 2004; Grill–Spector and Malach, 2004; Op de Beeck, Haushofer, and Kanwisher, 2008). In contrast, prototypical verbs involve predictions of actions, and their meanings rely primarily on the posterior middle temporal regions (Humphreys, Newling, Jennings, and Gennari, 2013; Lin, Lu, Fang, Han, and Bi, 2011; Revill, Aslin, Tanenhaus, and Bavelier, 2008; Wallentin, Nielson, Vuust, Dohn, Roepstorff, and Lund, 2011; Watson, Cardillo, Ianni, and Chatterjee, 2013), parietal lobe (Assmus, Giessing, Weiss, and Fink, 2007; Kemmerer, Rudrauf, Manzel, and Tranel, 2012; Noppeney, Josephs, Kiebel, Friston, and Price, 2005), and frontal cortex (Fazio et al., 2009; Filimon et al., 2007; Clerget, Winderickx, Fadiga, and Olivier, 2009; Michael et al., 2014).

Knowledge of Space

The third dimension of knowledge comes from extroceptive perceptions: the knowledge of space. Every object is recognized in a particular space. An object

without a space cannot be recognized. Thus, perception needs a space construct. Space is constructed around the body in motion and thus provides a safe base for the self. The tool for space perception is a proprioceptive sense.

Hippocampal place cells represent the spatial environment in the brain (Moser, Kropff, and Moser, 2008). It has recently been shown that place cells are part of a broader circuit for dynamic representation of self location (Barry and Burgess, 2014; Rolls and Xiang, 2006). This circuit of spatial representation in the brain includes entorhinal grid cells (Moser et al., 2008; Sasaki, Leutgeb, and Leutgeb, 2014), head-direction modulated cells in presubiculum (Taube, Muller, and Ranck, 1990), anterior thalamus (Taube, 1998), retrospenial cortex (Cooper and Mizumori, 1999; Takahashi, Kawamura, Shiota, Kasahata, and Hirayama, 1997), lateral entorhinal cortex (Hargreaves, Rao, Lee, and Knierim, 2005), parietal cortex (Kolb, Sutherland, and Whishaw, 1983; Nitz, 2006; Save, Guazzelli, and Poucet, 2001; Takahashi et al., 1997), and striatum (Hartley, Maguire, Spiers, and Burgess, 2003; Jog, Kubota, Connolly, Hillegaart, and Graybiel, 1999; Packard and McGaugh, 1996).

Knowledge of Time

The information in consciousness does not always provide us with information about the present. We can always attribute the knowledge of time to information, such as, "This is a memory," or "This is happening now," or "This might occur in the future."

There is always movement in the perception of time, even in the perception of space, objects, and the self. When we are talking about time, we are talking about the movement of "something" with regard to "something." Time "passes by." The movement of earth with regard to the sun creates time. In circadian rhythms, we talk about the changes in hormonal levels in the morning in comparison to the night. The sunset matches our urge to sleep, and the sunrise matches the end of our sleep. The external changes that are related to time match our internal changes. In this way, the knowledge of time is created in our consciousness, and objects begin to find a place in time, similar to how they find places in space. Thus, the four dimensional knowledge of consciousness is created.

In mammals, the circadian timing system is composed of virtually as many "clocks" as there are cells in the body. The master clock is located in the suprachiasmatic nuclei (SCN) of the hypothalamus and synchronizes the other central clocks, which are related to metabolic and reward integration and motor coordination (Lehman, Silver, Gladstone, Kahn, Gibson, and Bittman, 1987). Stomach, adipocytes, adrenals, pancreas, liver, and muscles are examples of organs and tissues that contain peripheral circadian clocks. The SCN synchronizes these organ and tissue clocks by using electrical, endocrine, and signaling pathways that impact the molecular mechanisms of the cellular clocks (Albrecht, 2012).

The SCN are not the only structures in the brain that display daily oscillations (Mohawk, Green, and Takahashi, 2012). Nuclei in the thalamus and hypothalamus, amygdala, hippocampus, habenula, and olfactory bulbs show such oscillations (Guilding and Piggins, 2007). The most robust rhythms, beyond those observed in the SCN, are found in the olfactory bulbs and in tissues that have neuroendocrine functions. These brain areas include the arcuate nucleus, the paraventricular nucleus (PVN), and the pituitary gland (Colwell, 2011). For example, SCN projections through the paraventricular nucleus–superior cervical ganglia pathway provide the dominant entraining signal for the submandibular salivary glands (Ueyama et al., 1999; Vujovic, Davidson, and Menaker, 2008). Sympathetic innervation from the SCN to the PVN to the liver results in daily rhythms of plasma glucose, presumably by directly influencing the rhythm of hepatic gluconeogenesis (Cailotto et al., 2005; Kalsbeek, La Fleur, Van Heijningen, and Buijs, 2004).

According to Northoff (2013), current neuroscientific approaches to phenomenal consciousness are insufficient because they apply a bi-dimensional model to consciousness: content and level. Northoff proposes that a third dimension, namely, the spatiotemporal structure that is provided by the brain's intrinsic activity, must be present for the generation of consciousness. This intrinsic activity and its spatiotemporal continuity structure organize the extrinsic stimuli in time and space. We agree with this view because the knowledge of time and space are necessary for the generation of "reality" in consciousness.

Grouping Consciousness According to its Content

Consciousness can be seen as a prediction tool which compares the incoming sensory stimuli with its already existing knowledge about the structure of the world as well as being a mounting tool for adding new knowledge with minimal predictive error. Next, we will discuss the contents of consciousness, which is shaped by this knowledge. In our view, consciousness can be grouped with regard to the different content which have developed from different phylogenetic stages: collective consciousness and individual consciousness.

Collective consciousness is shared by different members of the same community (e.g., species, races, country, family, cultures etc.). It includes two types of information: (1) information based on the DNA, which comes from ancestors of the same species, and (2) information that is gathered after birth, from the family and community that we live in. Information in consciousness that comes from our ancestors is related to survival and continuation of the species, such as primitive reflexes like suckling. Information that arises from our family is about rules, values, and the common views of the community in which we live. Examples are our cultural traditions and national values (such as the memorial of important national characters).

Collective consciousness helps to maintain the structure of the society and the continuation of the species, and it facilitates unity against a situation that overpowers personal strength. In Eastern culture it is often described as a "culture of relatedness or collectivism," where interpersonal relations are of central importance (Kagitcibasi, 1994). Collective consciousness is important for maintaining a partnership.

Collective consciousness firstly develops between the mother, or the care-giver in general, and the infant. It has been well-established that the face-to-face interactions of parents and infants occur quite early and are bidirectional (Ammaniti and Ferrari, 2013). Facial mirroring illustrates that there are interactions organized by ongoing regulations and experiences of mutually attuned interactions, which are fundamental to the developing sense of the "we." A high-intensity mirroring exchange creates in the infant a "merger" experience, defined also by neurobiologists Singer and Hein (2012) as emotional contagion in which there is no awareness that these emotions originate from another person. We understand other's actions through a mechanism of *resonance*, in which the motor system of the observer resonates whenever an appropriate visual and/or acoustic input is presented, although this does not necessarily imply the production of an overt movement. Stern (2004, p. 80) points out an interesting issue: "To resonate with someone, you may have to be unconsciously in synch with that person. You could move in synchrony, as lovers may do when they sit across a coffee table and trace a dance as they simultaneously approach and withdraw their faces from one another or move their hands together at the same instant." This resonance between the brain activities of two people can be a mechanism for facilitating the formation of collective consciousness. The baby mimics the behavior and affect of the mother and other people around him and receives rewards from them. Collective consciousness enables survival because, at this age, the baby needs care from others to survive. Until adolescence, collective consciousness is shared by the members of the family. As the adolescent tries forming bonds with other people, individual consciousness begins to appear.

Individual consciousness is about "me." It includes information about "my personal history," "my present," "my future," "my relations," and other related aspects. To develop an individual consciousness, one must have a collective consciousness, because individual consciousness is rooted in the internalized object representations in collective consciousness. Individual consciousness is more recognizable in Western communities and Western culture is often described as a "culture of separateness and individualism," where personal autonomy is valued (Kagitcibasi, 1994). Even though individual consciousness is necessary for the development of civilization and for providing creativity, the functionality and order of a society depends on collective consciousness. In individual consciousness, the ability to self-help and the ability to reject collective consciousness exist.

The Neurobiology of Collective and Individual Consciousness

One of the main candidates for the neural correlates of consciousness is neural synchronization (Fell, 2004; John, 2005). Through neural synchronization, neural activities in different brain regions reach temporal coordination and integration, and the content of consciousness remains attached. Accordingly, neural oscillations form the best candidates for understanding the neural substrates of these two different types of consciousness.

Neurons do not function in isolation. They are embedded in assemblies and networks that influence one another through excitatory and inhibitory synaptic connections. As a result, the neurons in a network are rhythmically activated and inhibited. This rhythmicity is reflected in the oscillations of the extracellular field potential that can be measured through recordings of local field potentials and through electroencephalography. Thus, brain oscillations can be defined as periodic fluctuations of excitability in groups of neurons (Buzsaki and Watson, 2012). There are five types of neural oscillations in the brain (Uhlhaas, 2012; Uhlhaas and Singer, 2010). *Delta* oscillations have a frequency of 1–3 Hz and are located mainly in the thalamus and neocortex. *Theta* oscillations have a frequency of 4–7 Hz and are located in the hippocampus, the sensory cortex, and the prefrontal cortex. *Alpha* oscillations have a frequency of 8–12 Hz and are mainly located in the thalamus, hippocampus, reticular formation, sensory cortex, motor cortex, and prefrontal cortex. *Beta* oscillations have a frequency of 13–30 Hz and, in addition to all cortical structures, they are localized in the subthalamic nucleus, basal ganglia, and olfactory bulb. *Gamma* oscillations have a frequency range of 30–200 Hz and are produced by neural networks throughout the brain. Accordingly, the neural networks that represent collective consciousness have predominantly slow oscillations (delta–theta), while the neural networks that have fast oscillations (gamma) represent individual consciousness. We have three proofs to support this assumption:

(1) We have suggested that babies and children predominantly have collective consciousness, while individual consciousness begins to develop at adolescent ages. This transmission from collective consciousness into individual consciousness parallels the age-related changes in the neural oscillations. Delta waves during nREM sleep increase steeply during the first years of life, reach a maximum in early childhood, and fall by 65% by 17 years of age. In contrast, nREM theta waves begin to decline much earlier (Feinberg, 1974). This observation has stimulated the hypothesis that during adolescence, the human brain undergoes an extensive reorganization that is driven by synaptic elimination. The parallel declines in the synaptic density, delta wave amplitude, and cortical metabolic rate during adolescence further support this model (Feinberg and Campbell, 2010).

(2) Synaptic pruning is part of a more general process of brain maturation that involves metabolic aspects (Chugani, Phelps, and Mazziotta, 1987; Jacobs et al., 1995), gene expression profiling (Harris, Lockstone, Khaitovich, Weickert, Webster, and Bahn, 2009; Somel et al. 2011), and functional changes (Feinberg and Campbell, 2010; Whitford, Rennie, Grieve, Clark, Gordon, and Williams, 2007). It has been found that adolescent maturation results in an increase in gamma oscillations in the medial prefrontal cortex (De Almeida, Jourdan, Murer, and Belforte, 2013).

(3) The maturation of higher cognitive abilities parallels the development of individual consciousness from collective consciousness. An increase in the cortical gamma activity has been shown to accompany the development of higher cognitive abilities, such as attention (Başar, Başar–Eroğlu, Karakaş, and Schürmann, 2000; John, Ahn, Princep, Trepetin, Brown, and Kaye, 1980; Ray, Niebur, Hsiao, Sinai, and Crone, 2008; Rodriguez, George, Lachaux, Martinerie, Renault, and Varela, 1999), perception (Başar et al., 2000; Gruber, Müller, and Keil, 2002; Lisman and Idiart, 1995; Rodriguez et al. 1999; Singer, 1999), memory (Başar et al., 2000; Fell et al., 2001; Gruber, Müller, and Keil, 2002; Fries, Fernandez, and Jensen, 2003; Miltner, Braun, Arnold, Witte, and Taub, 1999), and language (Benasich, Gou, Choudfhurry, and Harris, 2008; Eulitz, Maess, Pantev, Friederici, Feige, and Elbert, 1996; Pulvermüller et al., 1996).

The Role of Neural Synchronization during the Transmission of Information through the Brain Stem to the Cerebral Cortex

How does a neural synchronization occur? By linking together the neural activity at different discrete points in time, a certain degree of temporal continuity is constituted (Northoff, 2013). Gamma-band synchronization entails rhythmic inhibition of the local network, and the periods between inhibitions provide temporal windows for neuronal interaction. Two groups of neurons will therefore have a greater influence on each other when their temporal interaction windows open at the same time, i.e., when the rhythmic synchronization within the groups is also synchronized between the groups (Womelsdorf et al., 2007). An analogous phase-locking of the high-frequency oscillation power to the phases of the lower-frequency oscillations is described as phase-power coupling (Canolty and Knight, 2010; Sauseng and Klimesch, 2008). The synchronized oscillations begin to increase during the adolescent ages, because synaptic pruning increases functional connectivity (Kelly and Castellanos, 2014).

Until that time, there are some non-functional neural networks that continue to oscillate with delta and theta frequencies. It has been shown that the theta oscillations are necessary for long-term potentiation in the hippocampus (Huerta and Lisman, 1995) and for learning (Albers, Schmiedt, and Pawelzik, 2013). However, it is not clear how this circumstance occurs and whether it is linked to synaptic

plasticity. Most likely, oscillations can provide a suitable base for synaptic changes and send signals for pruning to natural pruners, especially those oscillations that have not formed any synchronization with other networks.

Schizophrenia may be considered as a disorder caused by failure of the functional neural synchronization and abnormal neural pruning processes. The idea that schizophrenia is a neurodevelopmental disorder that is caused by abnormal synaptic pruning is not new (see Faludi and Mirnics, 2011 for a review). The converging evidence from electrophysiological, physiological, and anatomical studies suggests that abnormalities in the synchronized oscillatory activity of neurons could have a central role in the pathophysiology of schizophrenia (Buzsaki and Watson, 2012; Uhlhaas, 2012; Uhlhaas and Singer, 2010; Voytek and Knight, 2015). The abnormal neural maturation and synaptic pruning in schizophrenia may result from failure of the formation of high-frequency neural oscillations and, thus, the dominance of collective consciousness instead of individual consciousness.

As is known, all stimuli do not reach consciousness. If that was the case, then we would be under the influence of a rain of stimuli and attentional processes would suffer. A stimulus can only reach consciousness if it has strength above threshold. This arrangement is true for both external and internal (e.g., thoughts) stimuli. In a previous paper (Ceylan, Dönmez, Ünsalver, and Evrensel, 2016), we proposed a neuroscientific mechanism about how unconscious mental events reach conscious awareness: by the locking of neural synchronization between two mental layers of consciousness and unconsciousness.

The most obvious role of electrical synapses is to couple the membrane potential of connected cells, which leads to an increase in the probability of synchronized action potentials within networks (Galarreta and Hestrin, 1999; Gibson, Beierlein, and Connors, 1999). This synchronous firing coordinates the activity of other cortical cell populations, and it has been reported that electrical synapses among GABAergic neurons can promote oscillatory rhythmic activity (Bartos et al., 2002; Blatow et al., 2003; Deans, Gibson, Sellitto, Connors, and Paul, 2001; Tamas, Buhl, Lörincz, and Somogyi, 2000), because GABAergic interneurons have many connections with cortical pyramidal neurons (Cobb, Buhl, Halasy, Paulsen, and Somogyi, 1995). The inhibitory post-synaptic potential (IPSP) determines the oscillatory type of that neural network (Wang and Buzsaki, 1996). For these purposes, GABA uses different subunits of its receptor. For example, before adolescence, the alpha 2 subunits are more active in the dorsolateral prefrontal cortex, and the alpha 1 subunit is more active after adolescence (Pinto, Hornby, Jones, and Murphy, 2010). This change in the subunits changes the kinetics of the GABA receptor, decreases the IPSP duration, increases the activation for the synchronization, and thus supports the development of individual consciousness in adolescence.

Developmental Stages of Consciousness

Above, we have proposed that consciousness can be grouped into two layers according to its content: collective and individual consciousness. Next, we will propose that consciousness has four neurodevelopmental stages: primitive consciousness, proto-consciousness, immature consciousness, and mature consciousness. The foundations of the brain's architecture are established during "sensitive periods" of neurodevelopment (Knudsen, 2004). Each sensitive period provides precursor neural structures to be used during the next sensitive period (Fox, Levitt, and Nelson, 2010). Brain development begins in intrauterine life and continues through the third decade. The development of consciousness should accompany the brain's development.

The number of neurons in a newborn's brain is more than the number of neurons in an adult's brain, but many of these neurons do not have functional synapses yet. After the birth, synaptogenesis begins, followed by a synaptic elimination and pruning process of the dendritic trees as well as of dysfunctional synapses, which lasts until adolescence (for a summary, see Bourgeois, 1997). Myelination begins during the prenatal period, but it continues until the third decade in the frontal cortex, where conscious thoughts take place (Sowell, Thompson, Leonard, Welcome, Kan, and Toga, 2004). At 12th–16th gestational weeks, thalamocortical afferents accumulate within the superficial subplate and grow into cortical plate-developing synapses (Kostovic and Milosevic, 2006). After the 34th week, EEG rhythmicity in both hemispheres becomes detectable, because long-range callosal connections are established (Vanhatalo and Kaila, 2006). However, the fusiform area for face recognition (Johnson, 2005) and the left hemispheric temporal lobe cortices for processing speech stimuli (Dehaene–Lambertz, Hertz–Pannier, and Dubois, 2006) function already in the newborn. Moreover, the main fascicles of myelinated long-range connections, such as the corpus callosum, cerebellar peduncles, corticospinal tract, and spinothalamic tract, are unambiguously identified at the age of 1–4 months (Lagercrantz and Changeux, 2009). The connections between these structures and horizontal cortical networks, which will be necessary for higher-order consciousness, will be established later.

Accordingly, in parallel to these neurodevelopmental stages, consciousness develops at four distinct steps. Primitive consciousness refers to the mental activity in intrauterine life., and it exists as much as the neural structures of the fetus allow. Thus, it is very primitive. A fetus is usually asleep but can respond to external stimuli such as touch, smell, and sound; but these responses are probably reflexive and subcortical. Proto-consciousness is a pre-verbal type of consciousness which exists from the newborn stage until the ages at which the baby begins to differentiate between "me" and "others" (probably at two years). This stage corresponds to the sensorimotor stage of Piaget's cognitive development architecture (Piaget, 1977). The right hemisphere dominates this type of

consciousness. The baby still depends on others to survive, but also begins to encounter new objects, and knowledge about the objects begins to accrue. As this knowledge increases, the need to have a more developed consciousness begins to arise. The baby at this age can differentiate between sensorial stimuli, such as differentiation between the mother's nipple and a plastic pacifier. Some of the information about the objects is placed in memory. These internal representations in memory will form the base for language development.

With the help of language development, the difference between the self and others begins to become evident. Immature consciousness corresponds to the pre-operational and concrete operational stage of Piaget's cognitive development. At first, there is no operational or logical thinking; thinking is governed more by appearance and intuitive reasoning. There is still partial dependency on others. But as the left hemisphere begins to dominate consciousness, objects become better recognized. There is a dominance of concrete thought. As the child grows, she often begins to make classifications and simple connections between objects. She begins to understand the difference between reality and fantasy. As the synaptic pruning process increases, the immature consciousness begins to turn into mature consciousness.

Mature consciousness corresponds to the formal operation stage of Piaget's depiction of cognitive development. In mature consciousness, symbolization is developed. There is significant differentiation between the self and others. There is abstract thought, deductive reasoning, and consciousness goes beyond concrete experiences. Consciousness reaches its final maturation stage as the frontal cortex reaches its adult form.

Relevance and Contribution to the Major Theories of Consciousness

Neurobiological Theories

Most neurobiological theories work from the premise that the neural correlate of consciousness (NCC) is some kind of neural cell-assembly. Bottom–up theories of this kind focus on specific neurons and neural activity as generators of consciousness (Butler, Manger, Lindahl, and Arhem, 2005). A representative bottom–up theory proposed by Crick and Koch (Crick, 1994; Crick and Koch, 1995; Koch, 1998) argues that the NCC at any given time will involve a sparse but spatially distributed network of neurons, and that its activity must stand out above the background of neural firing for at least 100–200 ms. The neurons directly involved in the NCC may have some unique combination of molecular, pharmacologic, biophysical, and anatomic properties. This proposal corresponds with our idea that the decoding process of information through the brainstem to cerebral cortex involves phase-lock of the synchronization of neural networks carrying that information.

Top–down neurobiological theories focus on large-scale neural structures and on activity of widespread brain regions (Butler et al., 2005). Edelman and Tononi (Edelman, 2003; Edelman and Tononi, 2000; Tononi and Edelman, 1998) have presented a top–down sensory approach that focuses on the general features of consciousness — such as complexity and unity. Their theory has three key tenets: that consciousness arises from the fast integration of a large amount of information within a dynamic core of strongly interacting elements; that re-entry, via reciprocal interconnections between regions of the thalamocortical system, mediates this rapid integration; and that the emergence of "primary consciousness" depends upon the integration of current sensory processing with previously acquired affect-laden memories. Edelman's "primary consciousness" refers to a state of having mental images in the present, without any sense of a person with a past and future, and "higher-order consciousness" refers to a state involving awareness of being aware (metacognitive processes). Integration of current sensory information with the already existing information as stated in Edelman's theory of consciousness is in concordance with our proposal. In our view, Edelman's "primary consciousness" refers to the consciousness produced by integration of current sensory information with the already existing knowledge of time, space, and objects by the process of prediction error. His "higher-order consciousness" refers to the integration of current information about the self with the already existing information about the self.

Functional Theories

Functional theories identify consciousness with a module, stage, or aspect of information processing, on the assumption that consciousness plays an important role in directing our waking behavior (Zeman, 2001). For example, Baars has proposed a model which identifies the contents of consciousness with the contents of a "global workspace" which can be broadcast widely through the nervous system to implicate the numerous unconscious specialized subsytems to the task in hand (Baars, 1998; Baars and McGovern, 1996). An alternative model proposed by Shallice (1988) emphasizes the role of consciousness in integrating activities of psychological sub-systems, such as goal setting and selection of actions. According to another theory, the function of consciousness is to supply us with insight into the minds of others by illuminating the workings of our own mind (Frith and Frith, 1999). We agree with the idea that consciousness plays a role in information processing in the brain as functional theories suggest and add the idea that the specific role of consciousness in information processing is to act as a prediction tool, as discussed above.

Social Theories

According to social theories of consciousness, sharing knowledge with one-self, in consciousness, and sharing knowledge with others, in social exchanges, are interdependent. It is argued that, at the conceptual level, the concept of one's own mind presupposes the concept of other minds (Strawson, 1974), and more recently, such knowledge has been described in terms of the possession of a theory of mind (Frith and Frith, 1999); some social theories broadly equate this with consciousness (Zeman, 2001). Theory of mind includes the notion that others may have different mental states than us, as well as the ability to make attributions about other's mental states. According to social theories of consciousness, our knowledge of our own mental states supplies us with insight into the mental states of others, and gives us the ability to predict mental states of others. The theory that one's own mind presupposes our understanding about the other's mind receives empirical support from work in child development showing that awareness of self and awareness of others are acquired in parallel (Parker, 1997). Of course, language plays a central role in this concept, and language itself is a social creation. This connection and relation between different minds may have helped the development of collective consciousness.

Neurodevelopmental Theories

Neurodevelopmental theories are not specific to consciousness. They aim to explain the development of cognitive functions in parallel to the development of neural systems. Piaget's cognitive development theory is such an example. According to Piaget (1977), development occurs in stages, with a qualitative shift in the organization and complexity of cognition at each stage. Cognitive structures named *schemes* are the means by which we interpret and organize experience. Early on, schemes are quite basic, and consist of reflexes like sucking and grasping. Later on, development proceeds as the child actively refines his knowledge of the world through "small experiments." Vygotsky (1978) criticized theories such as Piaget's, in which maturation is viewed as a precondition of learning but never the result of it. According to Vygotsky, individual development, including higher mental functioning, has its origins in social sources. He says (1978, p. 80): "Learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers." Vygotsky developed the concept of the *zone of proximal development*, which he defines as "the distance between the actual developmental level as determined through independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). Another theory of cognitive development is Bruner's theory of

representational media (Bruner et al., 1966). For Bruner, development is not seen as structural construction as in Piaget's theory. Instead, it occurs within the media by which the child represents his experience. The child constructs his world by successfully representing it as an enactive, an iconic, or a symbolic medium. The relations among these media give rise to conflicts, which includes a constructive mobility that may push development forward: if two representational systems do not correspond, as is the case if there is a conflict between "appearance" and "reality," the one being iconic and the other being symbolic, a disequilibrium arises that leads to the revision of the child's problem-solving method. Likewise, learning processes take place in the transition from one to another representational medium.

To summarize our view about the neurodevelopment of consciousness, we state the following: consciousness develops as a prediction tool in order to coordinate the interaction between the already existing knowledge of world (existing in more primitive neural structures such as subcortical areas and represented by slow neural oscillations) with the knowledge gathered by experience in the social world (formed in neocortex and represented by fast neural oscillations).

Conclusions

In this paper we presented a thesis about the development and neural correlates of consciousness. We proposed that consciousness is a prediction tool that compares incoming external stimuli with already existing knowledge with minimum predictive error. This knowledge includes the knowledge of self, objects, time, and space. If the external stimuli match this four-dimensional information in consciousness, the predictive error is minimized, and thus, the information that comes from the external stimuli is integrated in consciousness. If the information that comes from the external stimuli does not match the information in consciousness, then consciousness gives a predictive error and the two sources of information do not integrate.

We grouped conscious into two parts with regard to the features of the information that it includes. Collective consciousness includes information that comes from our ancestors which is coded in the DNA and information gathered from the family and community that we live in. Thus, we share the collective consciousness with different members of the same community. Collective consciousness helps to maintain the structure of the society and the continuation of the species, and it facilitates unity against situations that overpower personal strength. Individual consciousness includes specific and autobiographical information, which helps to maintain a decreased need and dependence on others.

We proposed that neural oscillations are the best candidates for understanding the neural substrates of these two different types of consciousness. Slow oscillations such as delta and theta represent collective consciousness, while fast

oscillations such as gamma represent individual consciousness. The change in the brain synchronization frequency from childhood to adolescence supports this assumption: in early ages, there is dominance of slow waves (and collective consciousness), while in adolescent ages, there is dominance of fast waves (and individual consciousness).

The second grouping of consciousness in this paper was related to the neuro-developmental stage. Here, we aimed to group consciousness into four developmental stages, which parallels the development of the nervous system from intrauterine life through adulthood. The grouping was necessary because one cannot assume that the nature of consciousness is the same in a fetus as in an adult: an underdeveloped, primitive nervous system can create a primitive consciousness, while a mature system can create a mature consciousness. With this idea, we identified four developmental stages of consciousness, namely, the primitive, proto, immature, and mature consciousness. The primitive and proto conscious include greater degrees of collective consciousness, while the immature and mature conscious include greater degrees of individual consciousness.

When explaining the fundamentals of the human mind with the findings of neuroscience, there is always a risk of over-simplification, and eliminative reductionism. Nevertheless, this paper should be seen as a cautious effort to move ahead slightly further than the previous philosophical and neuroscientific views about consciousness.

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