Implications of Neuroplasticity to the Philosophical Debate of Free Will and Determinism

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Abstract

Neuroplasticity, the capacity of the brain to induce changes in response to environmental stimuli, entails a continuous rearrangement of the neural network through a complex interaction between genetics and environment. Within this process, the plastic brain uses its internal representations to predict future conditions and proactively proceed to actions. It can be said that plasticity demands a rethinking of the concept of determinism as the process of coming-to-be is directly related to modifications produced by experience. Pure determinism and complete randomness are the two ends of a spectrum of positions relevant to the debate of the existence of free will. However, none conceptually supports free decision-making. How brain activity and the conscious experience of volition are related to one another has been a matter of significant research, with a plethora of findings indicating that early brain signals precede the self-reported time of the

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decision to act. The meaning of these findings, however, has been debated at both a theoretical and empirical level and the controversy is still ongoing. Consciousness is intertwined with free will along the dimension of time as it would otherwise be purposeless, taking place right at the next moment. Electrical activity of the brain is a measure of neurophysiological function and contributes to the understanding of processes that underlie high-order cognitive functions. A multidisciplinary approach in the study of free will could be designed in a way that philosophical concepts are connected to neural correlates by psychologically functionalizing them in terms of cognitive abilities. Such abilities are at the margins of conscious and nonconscious sensory information and are closely linked to brain processes of executive functions like attentional control and working memory.

Keywords

Neuroplasticity · Determinism · Free will · Consciousness · Attention · Psychophysiology · Sensory information · Brain activity

Introduction

Neuroplasticity, also known as neural plasticity or brain plasticity, can be defined as the capacity of the brain to continuously change throughout the development of lifetime in response to intrinsic or extrinsic stimuli, involving changes at different levels (genes, molecules, synapses, etc.) and associated with structural and functional reorganization. It is an intrinsic property which entails the physical and biochemical changes in the connections of the brain, linking past experiences with their effects on the present behavior of the organism. It signifies the ability of an entity to modify itself without disintegrating and it represents how evolution gave the ability to the nervous system to escape the restrictions imposed by its own genome and to adapt to environmental pressures, physiologic changes, and experiences (Cramer et al. 2011; Pascual-Leone et al. 2005).

The brain allows us to adapt our behavior to changes in the environment, enclosing these adaptations with emotions, consciousness, and reason. The flexibility of synapses between the neurons that compose the brain has been at the heart of scientific research for the last decade. Based on genes, flexibility shapes the brain in relation to life events, thus being the basis of learning, interpersonal relationships, and susceptibility to addictions. Plasticity is also a phenomenon connected to neuropsychiatric diseases, as well as brain recovery after damage produced by stroke or traumatic injury. Understanding plasticity and, in turn, manipulating specific neuronal pathways and synapses may have meaningful implications for therapeutic interventions (Mateos-Aparicio and Rodríguez-Moreno 2019).

The synapse is the point of contact and communication between neurons and comprises of the presynaptic and postsynaptic terminal (Moulson and Nelson 2008). It is a specialized site of transmission of either chemical or electrical signals. The structure and function of the synapse are highly dynamic depending on the activity, leading to neurogenesis or changes in the sensitivity of receptors and the activation of postsynaptic mechanisms (Kulik et al. 2019). These changes, involving cellular and molecular processes, have been directly linked to the concept of neuroplasticity and suggested to underlie learning and memory formations (Jasey and Ward 2019).

Neuroplasticity does not imply elasticity or permanent adaptability, something that would deprive a subject from a certain degree of determinism. Plasticity, however, contributes to the individuality of a subject. While it reflects a kind of determinism, at the same time, it "liberates" the subject from genetic determinism. Adaptive behaviors, learning, and memory are at the hierarchical top level of plastic-induced changes while molecular interactions form the base of the pyramid (Toricelli et al. 2021).

The notion of determinism directly confronts the idea of free will, with neuroscientists and philosophers being only some of the scholars who have reflected on this matter, providing a complex heterogeneity of responses (Rehman 2017). Among the philosophical implications of the existence of free will is ascribing moral responsibility, a concept which dates back to the Greek ancient philosophy; following the Aristotelian requirements for responsibility, namely control and knowledge, we infer that one is responsible if they have a sufficient level of control over an action and knowledgeable of what is pertaining to the action (Kormas and Moutzouri 2022).

The notion of a deterministic universe requires all phenomena and actions to be controlled by – or, otherwise stated, necessarily followed from – earlier states and conditions. Determinism has been reinforced by Galilean science and the progress of physical sciences, attributing unquestionable power to fundamental, exceptionless laws of nature (Hoefer 2016). A rigid philosophical tradition suggests that no choice is free unless without cause, meaning the will practiced independently of every causal influence, somehow in a "causative void." According to the laws of nature, states of the brain cause thoughts, feelings, and ultimately, choices. Brain shifts from one state to the next one as a result of prior conditions. Moreover, despite brains making decisions, there is no distinct brain structure or neural network that is characterized as will, nor is there a neural structure that is functioning in a "causative void."

Main Body

Neuroplasticity

Neuroplasticity is the "capacity of the central nervous system to undergo structural and functional reorganization in response to the environment, its afferent stimuli, and efferent demands" (Christiansen and Siebner 2022). It is any physiological change in the nervous system occurring as a result of activity induced by internal or external causes. The concept of plasticity is widely used in the field of neuroscience including phenomena across all levels of organization of the nervous system and related to both function and structure. Functional and structural plasticity may combine and coexist, as changes in one type may unavoidably be accompanied by changes in the other, for example, the change in number of receptors in a synapsis – reflecting a structural change – would be accompanied by a functional change, too. In this frame, structural plasticity processes are difficult to be separated from functional ones.

The basic mechanisms underlying neuroplasticity are considered to be maintained across life span. Variations, however, exist in the extent and degree of plastic changes, thereby distinguishing two types, the developmental and adult brain plasticity. The main distinguishing feature between the two types is that plasticity in the developmental phase occurs with passive exposure of the individual organism to the relevant stimuli during the critical periods, while adult plasticity mainly requires higher-order attentional mechanisms to detect and respond to the relevant information from the environment (Hensch 2005).

Research interest and experimental studies have focused on synaptic plasticity, i.e., the change in synaptic transmission, as it essentially constitutes the lower level of functional organization and it offers a broad area for practical study. At a higher level, plasticity takes the form of behavioral change, i.e., what we call learning. Synaptic plasticity may be functioning in terms of new connections, pruning of existing ones, transmission modification, or excitability modulation. Among the many forms of synaptic plasticity that have been described, the most extensively studied are the long-term potentiation (LTP) and long-term depression (LTD) of synaptic transmission. Special mention has to be given to the long-term potentiation (LTP) process, which involves persistent strengthening of synapses leading to a long-lasting increase in signal transmission between neurons (Abraham et al. 2019; Fu and Jhamandas 2020). LTP was first described by Bliss and Lømo in the 1970s and is now considered to be a fundamental cellular correlate of learning and memory formation (Fernandes and Contractor 2017), consisting of various molecular and cellular interactions.

Dominant-key factor is the receptor NMDA (N-methyl-D-aspartate), which has an inductive role, and the calcium ion, that helps in the expression and maintenance of the LTP phenomenon. During physiological synaptic transmission, glutamic acid is released from the presynaptic terminals, activating non-NMDA receptors (AMPA and KA), allowing the transmission of Na^+ and K^+ ions, creating depolarizations lasting some fractions of a second. When the potential is at rest, the Mg^{2+} ions block the NMDA receptors, while upon postsynaptic depolarization, Mg^{2+} ions are removed, thereby permitting the entry of Na^+, K^+ but also Ca^{2+} through the channel. Due to this process, a slow synaptic current is created, which prolongs the stimulation of the postsynaptic potential. The entry of Ca^{2+} in the postsynaptic neuron is of special importance, because this concentration change activates intracellular signaling pathways, thus contributing to the strengthening of LTP (Nicoll 2017).

The nervous system coordinates the function of the body organs, aiming at the homeostasis of the internal environment as well as the appropriate responses to the external conditions that act upon it. In order for the nervous system to function, an integrated information exchange system is required, in which endocrine and immune systems are also involved. The nervous system receives – through the sensory organs – and analyzes in milliseconds, direct and indirect influences from the external environment. Learning and memory processes involve the comparison of these influences with previous ones and their storage while organizing the appropriate response (i.e., behavior) through skeletal muscles and glands. This type of task is feasible due to the genetically predetermined differentiation of the nerve cells and the lifelong plasticity of their synapses. Nerve cells achieve communication with the environment in order to organize the behavior. The main function of the nerve cells is to receive, process, and transmit information through a powerful dynamic interaction between multiple levels of brain organization, continuous adaptation to the environment and learning.

An individual's brain architecture is not static but is undergoing continuous modification through influences from internal and external factors in combination with genetic parameters connected with the physiological cycle of development. Encompassing the concept of change, plasticity successfully reflects the idea of the mnemonic phenomenon as an ever-changing status of the nervous system. A central assumption in the modern neuroscientific studies is that all brain functions observed through behavior are based on the activity of neurons. The mnemonic procedure, based on different approaches, is defined as an established, stable data-storage process. Despite the fact that the nerve cell is not considered the fundamental unit of memory, understanding the cellular and molecular basis of learning and memory is where to begin in order to elucidate the relevant behavioral processes (Sweatt 2010).

Donald Hebb's work on the neural mechanisms has been considered a landmark in plasticity research with his postulate that when a neuron repeatedly drives the activity of another, their connection becomes strengthened (Hebb 1949). Hebbian plasticity addressed the question of causality and the discovery of spike timing-dependent plasticity (STDP) provided a framework for understanding synaptic learning and circuit plasticity according to the timing of neuronal spikes. If presynaptic spiking precedes postsynaptic spiking within a window of some tens of milliseconds, then the connecting synapse is strengthened and LTP is induced. The synapse is weakened in case of a postsynaptic spike before a presynaptic spike, leading to LTD (Foncelle et al. 2018; Stent 1973). Numerous studies have revealed how neural circuits adapt their weights depending on the relative spike timing and firing rate pattern of pre- and postsynaptic neurons, the spike timing-dependent plasticity (Bi and Poo 1998; Dudek and Bear 1992; Markram et al. 1997; Nelson et al. 2002). For most STDP forms, in case the time window between pre- and post-spiking exceeds 80 ms, long-term synaptic changes do not take place (Bi and Poo 1998; Markram et al. 1997). Interestingly, the temporal properties of STDP act in concert with neuromodulator receptor activation, such as dopamine, which can increase or decrease the threshold for plasticity induction (Pawlak et al. 2010).

The interest in within-individual variation is increasing (Stamps 2016) with studies indicating that individuals, when assessed two times or more in the same context, exhibit different behaviors. The degree of variation may also differ among individuals as a result of an interaction between internal states and external stimuli further mediated by behavior. The interplay between an individual's internal state and the external environment is mediated by behavior and further fuels the subsequent variation in behavior at different levels (Henriksen et al. 2020; Mitchell and Biro 2017). Behavioral plasticity can be on its own “developmentally plastic.” Research findings support the hypothesis that differences among individuals in prior experiences may account for differences in behavioral plasticity observed at a certain age (Stamps 2016).

Neuroscience, Determinism, and Plasticity

Describing the brain as a biological system governed by natural laws has given rise to the contemporary position that decisions and human behaviors are the determined outcome of prior mechanical processes. In this frame, and in principle, if we could understand a subject’s brain architecture and chemical processes, we could predict the response to any given stimulus (Erinakis 2020). Human actions are seen as part of the natural world and determinism appears overwhelmingly relevant to neuroscientific evidence.

Plasticity plays a critical role in how we approach determinism through the neuroscientific lens. The plastic brain has been confirmed to maintain a perpetual relationship with the subject and its environment. Based on the experience captured by the nervous system, an imprinted event leaves a trace which remains in the memory and which can function in various ways by correlating with other traces. In neurobiological terms, this mnemonic trace is dynamic, modifying what priorly existed. Essentially, it can be implied that the subject is ever-changing, rebeginning its course on a “tabula rasa” on which new traces are to be imprinted. Plasticity is thus contributing to the emergence of individuality, and in turn, diversity. With the new data, genetic determinism is limited. The level of expression of a particular gene can be determined by the particular characteristics of the experience. The complex integration of genetic predisposition with environmental factors, replaces the earlier differentiation between these two fields (Ansermet and Magistretti 2004).

The plasticity mechanism reforms the neural circuits in such a way that the same stimulus may lead to various responses. As the English neurobiologist Robert Terner said, “we never use the same brain twice.” That being said, plasticity can act within specific limits, the ones of the functional neural network. The variation in response does not necessarily imply a complete freedom, as the network itself and the plasticity mechanisms are subject to biological restrictions put forward within the frame of biological predeterminism. Brain may, on the one hand, constitute the biological factor that is in control of one’s self. However, neuroplasticity is a factor which “dissolves the cerebral determinism of the pre-programmed neural machine” (Kroupa and Simoniti 2020).

A biological system, through plasticity mechanisms, rearranges itself when moving from one stimulus to the next, generating inter-temporal differences in responses, depending on the – every time – state of the system. It can be said that plasticity demands a rethinking of the concept of determinism as the process of coming-to-be is directly related to structural and functional modifications produced by experience.

Among the first refuters of determinism has been Epicurus, the ancient Greek philosopher who had suggested that there is a margin for freedom of action due to random, undetermined "swerves" of atoms in their otherwise deterministic paths (Long and Vertzagia 2020). The swerve (*parenklisis*) describes a displacement of an atom from its appointed trajectory to an adjacent one with a minimum distance, thereby leading to the refutation of determinism. The theory of Epicurus has been characterized as comparable to modern quantum indeterminism (Sedley 1998). However, the swerve may offer an escape from determinism but indeterminism or chance as the source of action is not also directly involved in producing a free action (O'Keefe 2021).

Pure determinism and complete randomness are positioned diametrically opposed in the debate of brain functioning with reference to the existence of free will. However, they can both be considered free will's rivals. On the one hand determinism abolishes the "option to do otherwise," a condition inextricable in the description of free will (Savulescu and Protopapadakis 2019). On the other hand, randomness is not the same as freedom. Random actions do not support the existence of free, rational decision-making and abolish the meaning of the agent being the generator of an action. Free decision-making, though not determined, cannot be random. Indeterminism has gained increased reputability, especially with the progress and discoveries in quantum mechanics. Indeterminism though and randomness do not imply one another and the association of indeterminism to free will has been acknowledged as a more complex relationship to comprehend (Joober and Karama 2021).

A critical prerequisite for free will is the dissociation of the chain of causality, although it is not by itself sufficient to define what free will is. In this respect, William James enunciated a two-stage model whereby chance (denoting the indeterministic free component) is separated from choice (denoting the determinate-like decision following causal rules and originating from one's character, values, and desires at the time of decision). The two stages build a temporal sequence in which chance presents random alternatives leading to a determined choice which gives consent to only one possibility (Doyle 2009). In the twentieth and twenty-first centuries, the two-stage approach to free will, essentially separating the free first stage and the willed second stage, has been advocated by many renowned philosophers, psychologists, mathematicians, physicists, and neuroscientists (Brembs 2010; Kane 2005).

Logical Dependencies Among Free Will and Consciousness

Most of the responses of an organism enclose a component of will, employed in order to avoid or identify situations compatible to its survival. This biological – and teleological – line of thought could contribute to the debate on the existence or not of free will. The teleological nature of human thinking serves the description of actions in terms of outcomes (Kotchoubey 2018). Voluntary actions regard future events. They include a certain plan or an internal concept of how a specific goal will be achieved. Such goals are sustained as “future memories” and comprise an inherent component of consciousness (Ingvar 1985). Today, consciousness is acknowledged as retaining a personal character throughout the life span of an individual and is an essential background for the advanced intellect (Kormas and Moutzouri 2020).

Sensory representation is not solely defined by the relevant stimuli but is also influenced, both in terms of amplitude and content, by prior expectations and by states of attention and working memory. Such evidence supports the account of unconscious inference, wherein bottom-up sensory stimulus combined with top-down prior beliefs generate the action taken by an agent (Isomura 2022). In neurophysiological terms, optimal inference is probably associated with post-hoc modulation of synaptic plasticity provided by neuromodulators – such as dopamine, noradrenaline, acetylcholine, or serotonin – a mechanism which is not yet elucidated. In this way, synapses are modulated also based on more global information about the performance of the whole network and drive neural activity in performing Bayesian inference (Kuśmierz et al. 2017).

Conscious mental functions, like will is, produce energy potentials at the neurons which are necessary for the generation of the muscle contractions producing behavior, ranging from simple moves to coordinated actions and speech. Voluntary actions do not immediately start at the primary motor cortex, but it is believed that energy potentials at other brain neurons lead to energy potentials at the neurons related to information output of the motor cortex (Fried et al. 2017). Behind each voluntary action, three distinct steps can be identified. The first is the awareness of the need to achieve a future goal. Subcortical structures participate in the process of shaping a goal. Mechanisms of attention, particularly of target-oriented type, are included in this step. The second step includes the execution of the voluntary action in itself. Within this timeframe, feedback and feedforward control may be applied by the prefrontal mechanisms as well as by structures around the central Rolando fissure. The third step follows the success of the goal of the voluntary action and completes the internal representation of the action. Subcortical mechanisms referring to the highest level of emotion are involved in the general assessment of whether the action has been successful or not.

Electrophysiological studies focus on cortical events taking place some seconds before and after a voluntary action. Electroencephalography (EEG) is an electrophysiological, noninvasive technique for the monitoring of electrical activity of the human brain, detecting the summation of neuronal excitatory and inhibitory postsynaptic potentials. EEG is employed to assess neurophysiological function and contribute to the understanding of processes that underlie high-order cognitive functions. Well-established electroencephalographic activity has been captured, either when spontaneous by conventional electroencephalography or the electroencephalographic activity induced by the exposure to stimulation of different quality, intensity, or/and frequency. A conventional EEG recording generates a frequency spectrum dominated by oscillations or brainwaves. The voltage changes in the brain that are time-locked to a specific event are the event related potentials (ERPs). ERPs represent neural activity of interest that is temporally related to a specific stimulus (Britton et al. 2016; Sur and Sinha 2009).

The prefrontal cortex identifies the temporal arrangement of the sensory information input, thus recognizing causality in the sensory input. The relationship between will and prefrontal activity is in agreement with the opinion that frontal and prefrontal parts of the cortex are related to the serial programming in the timing of motor behavior, speech, and cognition. A prerequisite for physiological will is the establishment of a physiological memory for the future (Ingvar 1983).

How brain activity and the conscious experience of volition are related to one another has been attracting the interest of neuroscientists, philosophers, and psychologists in recent years. Consciousness is a complex function that enables a subject to intellectually conceive the status in which he/she is at a given moment and to have an idea about his/her future status. It is a subjective awareness of the senses, the beliefs, and the intentions of the psychological aspect of life. In other words, what it really means to be conscious is to know that one is at a certain location, living in one's body a certain life and that the things that are in one's mind are representations that only belong to oneself and not in another organism. This knowledge is a result of the constant interaction of the nervous system with the organism in which it is located and without which it could not exist.

The relationship of consciousness with free will could be briefed in what has been suggested by John Searle: "only for a conscious agent is there a problem of free will, and if free will does exist, it can only exist in conscious agents" (Searle 2010). Free will and consciousness, if existing, are intertwined in the web of time. Consciousness would otherwise be a purposeless activity taking place right at the next moment. Free will makes its presence significant by limiting the element of surprise, provoking an outcome which we have predicted. To the extent that it is a logical concept, it is conceivable as dependent to the fact that its carrier is somehow entangled in a flowing present moment. It seems to be dependent on the flowing time and indeterminism. If the universe was nondeterministic, there are indications that consciousness is connected to the formation of outcomes, because it is well-tied with the timeline on which events seem to occur.

If consciousness and free will are both real, then consciousness should bind itself to the physical hypostasis of the brain in a way that it minimizes conceptional conflicts. During a voluntary action, consciousness has by itself dispersed across a sequence of time moments unifying them to the unique experience of the moment of volition. Indeed, what is consciously perceived – mainly relying on the experience of time gaps between reasons and decisions – is that we are the ones who decide and do.

The Readiness Potential and the Libet Experiment

The brain processes involved in the design and initiation of voluntary action are of great interest for understanding the relationship between conscious decision-making and neural movement control. The brain activation which leads to a simple voluntary action has a component which changes through time (readiness potential, RP) and which can be measured. The RP, as described by Kornhuber and Deecke (2016), is the surface-negative cortical potential which increases with intentional engagement and decreases with indifference. Since it has been first reported, RP has been proposed as a preparatory signal leading to the production of voluntary movement (Shibasaki and Hallett 2006).

In a series of emblematic studies, Libet and colleagues provided empirical data that the brain decides to initiate or at least prepare the initiation of an action before the subject reports to be aware that such a decision has taken place. Researchers used a "mental chronometry" to determine the exact time that the participants felt to have taken a conscious decision to initiate an action. It was suggested that this was the time that they intended to initiate the action. This time, termed "W time" by Libet, was found to succeed RP by a few hundred milliseconds. Observing that the neural events associated with an action can be traced some hundreds of milliseconds before the participants become aware of their intentions, led to a plethora of philosophical postulations regarding volition and free will (Libet 2002, 2003; Libet et al. 1983).

Libet's experiment has been extensively discussed among scholars with conflicting interpretations on whether results point towards the direction of determinism and the refutation to the concept of free will or whether the experimental setting has even a relevance to the question of free will (Lavazza 2016). Libet suggested that the function of conscious will is not to initiate specific volitional actions but to apply conscious control by vetoing the cortex processes preceding the actions (Libet 1999).

It may not be a surprise though, that neural events precede conscious awareness since we are not conscious of all information transmitted via the senses towards the brain and we are not aware of all functions that underlie thoughts emerging to the conscious level. Subjective awareness, whatever it may entail, should be connected – fundamentally – to physiologic alterations in the central nervous system. It has been suggested that Libet's findings are compatible with the theory that it is brain events that cause causation and action, and not conscious intention in itself. According to Wegner's theory of apparent mental causation, will is only experienced because people interpret their thoughts as the causes of their actions. But the experience only relates to what is portrayed by our minds as the apparent causal sequence while the real causal mechanisms are not presented in consciousness. Brain events are the ones which cause intention and action, while on the other hand, conscious intention cannot produce action. Intention reflects the direction of activity while attention defines the target object and reflects the quality of activity. A person first anticipates the object to be able to identify intention. In other words, the feeling of intention is attributed after the event. This follows three principles: (a) the principle of priority, meaning the fact that thought is required to have preceded the action for the production of the feeling of free will; (b) consistency, referring to the content of thoughts to be in correlation with one's actions while a sense of control is shaped; and (c) exclusivity, meaning that thought cannot be accompanied by other causes, one should not believe that there is some kind of external influence (Wegner and Wheatley 1999).

Whether consciousness is a cause for human action or it is just an epiphenomenon has been one of the long-standing questions in the field of philosophy. Shifting from a nonconscious processing to conscious awareness is one of the great mysteries of neuroscience. It has been suggested that the timing of being consciously aware of something may reflect the completion of a decision-making process (Dehaene et al. 2014). Consciousness may have no selective, executive, controlling, or meta-cognitive function (Earl 2019), but has the exclusive ability to provide content in a way that it can be used by working memory, decision-making centers, metacognitive centers, and autobiographical memory. The treatment of consciousness as an epiphenomenon holds another challenge for the existence of free will, since decisions in this frame are emergent and cannot be considered causes of actions (Balaguer 2019).

Brain Activity and Psychophysiological Significance

Brain processes involved in the design and onset of voluntary actions are crucial in understanding the relationship between conscious awareness and neural control of movement. Our brain is constantly active while the spontaneous activity created by the neurons is organized in a complex system of rhythmic activity across five distinct frequency ranges: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (13–20 Hz), and gamma (20–100 Hz). The rhythmic activity is shaped by populations of neurons which fire at the same time and the wavelength of the rhythm is the one which determines the time margins for processing and the extent of activation of neural circuits. In this way, neuronal activity can be harmonized and coordinated across dispersed brain areas. Slow oscillations, such as theta, connect multiple neurons across extended, large-scale brain networks (Begus and Bonawitz 2020).

Each EEG rhythm (e.g., delta, theta, alpha, beta, and gamma) marks the beginning and the end of the coding/decoding and the transferring of information to the central nervous system during the perpetual interaction of the organism with the constantly changing environment. Based on this reasoning, the EEG rhythms reflect discrete functional missions of the CNS. Regarding the psychophysiological meaning of delta EEG activity, it is considered to reflect the function of neural circuits that underlie the transfer of information to consciousness (Frohlich et al. 2021). Theta brain activity is likely to reflect the registration of constructive information in the long-term memory. It is originating in the cortex and is estimated to represent a binding rhythm that temporally connects functionally connected neural circuits in order to ensure the process of memorization (Begus and Bonawitz 2020). It has been argued that the alpha EEG activity represents the functional neural interconnection, in particular the activity that inhibits the “noise” during the transmission of information through the working memory. Alpha EEG activity is related to learning, alertness, calmness, mental coordination, and mental composition (Sowndhararajan and Kim 2016. Beta EEG activity is estimated to reflect the function of the neural circuits that are subject to maintaining the inertia (status quo) of the sensory-kinetic and cognitive phenomena, during the interaction of the organism with its contextual environment (Wheaton et al. 2008). On the psychophysiological significance of gamma EEG activity, the first position supports the view that gamma EEG activity reflects the function of neural circuits that act as a reference time frame, in relation to sensory stimulus decoding. The second position supports the idea that gamma EEG activity affects the communication of neural circuits, in order to ensure the coherence of their communication. Lastly, it has been argued that gamma EEG activity coordinates the individual neural circuits that affect sensory composition (Buzsaki et al. 2008).

One of the first rhythms associated to cognitive functions is theta. It has been suggested that it is a measure of top-down control for the selective codification of information and the activation of a frame into which the future object is presented and embodied. Theta-related neuronal activity defines the memory encoding retrieval and mediates the communication of distant brain areas. Maybe one of the most influential theories related to the conscious experience of voluntary action was the suggestion that theta activity is present only during voluntary or intentional movement (Buzsáki 2005). Frontal theta activity has been suggested to function as a kind of alarm signal prompting for the engagement of cognitive control (Rajan et al. 2019).

Attention Mechanisms

Today, there is an increasing consensus arguing in favor of the hypothesis that there is a clear distinction between attention and consciousness. Within this frame, attention is believed to choose among the unconscious perceptual representations originating from the external environment or from memory those which – at the time following – become conscious through the neural correlates of consciousness. The neural correlate of consciousness is the minimum sum of neural events and mechanisms adequate for a specific conscious “percept.”

Electrophysiological brain activity and ERPs in particular offer an objective measure of cognition-related activity as they reflect information processing data, otherwise inaccessible with self-report or conventional behavioral methods. Several evoked waveforms have been well documented to be associated with specific processing functions. In this respect, the amplitude and timing of the positive and negative fluctuations are considered to index underlying functions. One of the most extensively studied components (component waves of the complex ERP waveforms of ERP) is the P300, a positive wave that peaks approximately 300 ms poststimulus onset and provides information about cognitive functions of the brain. It has been related to processes in function with the allocation of attention for the initiation of action, decision-making, and updating memory representations (Papageorgiou et al. 2009, 2016). Other significant indices related to higher order cognitive functions are P50, N100, and P200. An index of early aspects of attention, involved in the pre-attentive filtering of information, is considered to be the P50 waveform, while N100 is considered to be related to the triggering of attention. P200 is suggested to be involved in the allocation mechanism of attention and initial conscious awareness of a stimulus (Lijffijt et al. 2009).

The first 200 ms of brain activity that correspond to the early perceptual processing include bottom-up processes and belong to a first preconscious stage which lies outside the center of attention. The conscious evaluation is associated with delayed events like the firing at P300. For example, passing the threshold for a hearing or visual conscious perception is accompanied with the presence of a P300 wave in the prefrontal cortex. The intense neural firing can be confirmed with EEG by measuring the brain wave 300 which starts 300 ms after the projection of an image on a screen monitor. If attention to the selected content lasts for more than 200 ms of the preconscious stage, those sensory perceptions are introduced to the global neuronal workspace and in the next 100–150 ms, they are amplified and become conscious. On the contrary, without the P300 wave, the electric activity disappears and the appeared image is not captured by consciousness. Information does not enter the global neuronal workspace and remains part of the nonconscious (Mashour et al. 2020).

Plasticity and Freudian Concepts: The Unconscious Phantasy

An all-encompassing brain perspective acknowledges it as a system incorporating a model of the world and generating predictions. These predictions are constantly tested and updated through the coupled processes of perception and actions, which are treated as inferential. At a point in time, an individual changes future expectations based on processing sensory evidence. A specific perception taking place creates a prediction error based on prior expectation and changes the expectation for the future. This process, characterized by Friston as active inference, has as a goal to generate the most accurate model so as to guide the most adaptive behavior (Paulus et al. 2019; Solms 2019). The imprint, transcript, and association of traces left by experience are carried through with the mechanisms of synaptic plasticity. The experience itself is not just the external event but also the event inscribed and transcribed by the plasticity mechanisms. It is almost impossible to restore a direct connection with the actual event conceived by perception. On the contrary, consciousness is fed by phantasy in the same way that it is fed by perception, defining the actions and the psychic activities of the subject. Phantasy creation leads to a new stimulation of the neural instrument taking the place of the external stimulus. The predictions of the model are the analogues of what Freud had termed unconscious phantasies (Solms 2019), when suggesting that internal stimuli stigmatize the mental life of an individual.

Following Freud's approach, the experience and its perception give rise to the first psychic trace which can be paralleled to the synaptic trace. Lacan's signifier, i.e., the signal of perception, is positioned at the same level as the modification of the synaptic effectiveness, corresponding to Freud's psychic trace or neurobiology's synaptic trace. Despite, at first, each signifier being associated to a unique experience (signified), the trace itself can then be associated to other signifiers, originating from separate experiences, and lead to the formation of a new signifier which has nothing to do with the initial signified imprinted. The signifier is the vocal identity of the object determined while the signified is functioning as an informational unit. When the brain perceives and imprints stimuli in the form of traces originating from the external world, there is a certain correspondence between a trace (signifier) and the external reality (signified). This correspondence is of conscious nature and is related to cognitive processes, essentially being the base of learning and construction of conscious and retrievable memories. However, as a series of transcriptions take place, the initial imprint may abandon the conscious level and shape an artificial element of the psychic reality, irrespective of the external reality. This unconscious internal reality created by plasticity mechanisms is unique for each individual and rearranges in different ways the representation maintained by perception (Ansermet and Magistretti 2004).

Psychophysiological Entities Articulating Voluntary Propositions

Psychophysiology is the discipline which examines the relationships between physiological signals and psychological processes taking place prior to, parallel to, or post to the responses. In this context, psychophysiology uses the objective physiological measurements in order to interpret the underlying psychological processes. The interpretation is possible through the integration of data generally encompassed in the frame of a biosocial continuum. Across this continuum, the objective measurement of biological data is evolutionary wedded to the personalized subjective experience.

Psychophysiological measurements may provide invaluable tools in delineating the borderline between conscious and unconscious perceptual experience. The target would be to connect philosophical concepts with neural correlates via psychological functionalization in terms of skills and cognitive abilities. Such skills and abilities do not necessarily infer constant conscious control of decision-making and action. Empirical psychology can act as a bridge between free will manifested in behavior and underlying brain functions.

The feeling of having reached a decision corresponds to meeting a threshold that marks the moment at which the accumulated evidence reaches a certain boundary. The accumulated evidence is essentially the sensory information collected over time by neuronal populations in a process providing an explanation for the speed and accuracy of various types of decisions (Zhang 2012). In free-response experiments (information-controlled paradigm), reaction time demonstrates the termination of a decision, while in controlled-duration experiments (time-controlled paradigm), the only indication is the remembered clock location coinciding with the time of the feeling of having decided. In a random dot motion discrimination task, extensively employed to investigate the neural mechanisms of perceptual decisions, it has been demonstrated that the time at which subjects reported their decision to have taken place does indeed reflect the time of decision termination (Kang et al. 2017).

It has not been elucidated whether representations biasing subsequent voluntary imagery are genuinely nonconscious or not. Recent evidence that activation patterns in the primary visual cortex, emerging spontaneously without the subject's engagement predict the content and the strength of future voluntary imagery, has been suggested to indicate that a – possibly – conscious decision is the outcome of weak neural representations. This explanation has been put forward on the basis of a dissociation between a decision and predictive neural signals (Koenig-Robert and Pearson 2019).

Concluding Remarks

Describing the brain as a biological system governed by natural laws makes determinism overwhelmingly relevant to neuroscientific evidence. Determinism abolishes the "option to do otherwise," a condition inextricable in the description of free will (Protopapadakis 2017). Free will depends on non-determinism. Otherwise stated, while non-determinism does not demand free will, the opposite cannot be stated. The interplay of consciousness and determinism is also interesting as consciousness is an integrative function of perception, memory, and planning, with free will connecting it to the motor system. The present moment becomes a conundrum revealing that the very best among evidence on consciousness are too close to us to observe.

A significant body of literature and neuroscientific findings point to the conclusion that early brain signals, or decision-related neural activity, precede the self-reported time of the decision to act. The meaning of these findings, however, has been debated at both a theoretical and empirical level and the controversy is still ongoing.

A multidisciplinary approach in the study of free will could be designed in a way that philosophical concepts are connected to neural correlates by psychologically functionalizing them in terms of skills and cognitive abilities. Such skills and abilities are at the margins of conscious and nonconscious sensory information and are closely linked to brain processes of executive functions.

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