Evolutionary origin and the development of consciousness

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A B S T R A C T

This review seeks to combine advances in anthropology and neuroscience to investigate the adaptive value of human consciousness. It uses an interdisciplinary perspective on the origin of consciousness to refute the most common fallacies in considering consciousness, particularly, disregarding the evolutionary origin of the subjective reality in looking for the neural correlates of consciousness and divorcing studies in neuroscience and behavioural sciences. Various explanations linked to consciousness in the field of neuroscience, supplemented with the theoretical explanation of an experience as an ongoing process of overlap between intrinsic neural dynamics and stimulation can be summarised as the stochastic dynamics of one’s control system experienced by the individual in the form of subjective reality. This framework elaborates on the world-brain research program and lays foundation for the quantitative description of one’s qualitative feelings and naturalistic science of consciousness. Furthermore, this study highlights the philosophical perspective of the inseparability between the physical correlates and the subjective reality contributing to the realistic ontology of conscious processes.

1. Introduction

An individual’s consciousness comprises the feelings of pleasure, anger, excitement, and depression, along with complicated thoughts. While thoughts can be shared, one’s experience is always construed from an individual’s own perspective, which suggests the existence of subjective realities. However, contemporary science primarily employs the notion of consciousness to denote one’s responsiveness to the environment as described from an objective third-party’s perspective. Conversely, philosophy and humanities mostly promote the concept of mind that is assumed to differ from the physical reality. Such inconsistencies may encourage irrational ideologies, populism, and various biases. Herein, I demonstrate that the evolution of subjective reality and human consciousness is justified, by summarizing the recent advances in behavioural research, while supplementing the view of neuroscience and other disciplines that provide sufficient knowledge to integrate objective and subjective perspectives on the conscious process. This framework assumes the direct identity between the moment of experience and the current stochastic dynamics of neural overlap that the organism experiences as their subjective reality. This has been possible due to the synthesis of the most recent theoretical advances in neuroscience, particularly, “spatiotemporal neuroscience” (Northoff, 2018; Northoff and Lamme, 2020; Northoff et al., 2020), “thermodynamics of thinking” (Buxton, 2021), and understanding the Self within a context (Koban et al., 2021). The suggested framework contributes to the realistic ontology of subjective reality and consciousness, enables clarification and differentiation of the former from the latter, and bridges the “explanatory gap” between investigating basal (Lyon et al., 2021) and higher-order cognition (Barron et al., 2021; Deweerdt, 2019), as well as natural and social sciences (Feinberg and Mallatt, 2019).

1.1. The timeliness of research

Using various research strategies in one framework can advance science since there is currently no undisputed explanation with regard to how the conscious experience originates and why (Boly et al., 2013; Koch, 2018; Northoff and Lamme, 2020; Reardon, 2020; Schneider and Velmans, 2017; Sohn, 2019). Scientists have focused on the particular manifestations of subjective reality and cautiously commented on the nature of consciousness. However, certain concepts warrant scientific definitions of one’s ability to experience what is happening to them. Treating non-responsive patients (Demertzi et al., 2019; Huang et al., 2020; Luppi et al., 2019; Sohn, 2019) is critical to determining the nature of consciousness, as well as whether a non-responsive individual (or hospital patient) feels something. Furthermore, pain management is also essential since the current concept of “pain” is highly linked to one’s subjective apprehension of the threat and intersubjective space (Cohen et al., 2018) and is not divorced from the concept of “social pain” (Bélanger, 2021). Artificial intelligence can help us better understand...
performed functions; however, imitations of particular behaviours remain limited (Dehaene et al., 2017), whereas engaging in an activity requires an embodied interaction with the environment (Segal and Clark, 2019). Studying the human neural system is also essential since extensive collection of data without an understanding of the natural consciousness may be limited (Abbott, 2020; Fregnac, 2017). Several ethical challenges concerning artificial intelligence remain to be addressed (Yuste and Goering, 2017), including the creation of human brain organoids, which can produce activity patterns resembling those in premature babies (Reardon, 2020).

1.2. Philosophical context

One of the biggest issues in contemporary science is establishing the ontological status of human consciousness and subjective reality as a broader concept. Although dualistic ontologies can be traced back to the religious worldview, today they appeal to scientific data as well. Thus, it may be argued that an objective description of physical processes in one’s body does not consider one’s inner experience; hence, it cannot explain consciousness. Based on this, any functional process may only be a matter of a system’s complexity that can be performed without any inner experience; nevertheless, we experience the events in our lives. Therefore, one can infer that investigating the objective process in one’s body cannot explain “why” they are accompanied with some subjective feelings, arguing for the irreducibility of experience with respect to objective processes (Chalmers, 2018). The contrary view asserts that the presence of some subjective reality is an illusion. Although illusionism in understanding consciousness does not mean that subjective reality lacks causative power on organism’s behaviour (Frankish, 2017), scientific studies should focus on revealing “what happens” in the neural system when one encounters an experience (Dennett, 2018). Besides these two general approaches, there have been many attempts to demonstrate how subjective experiences emerge from the physical processes in the body, and one of the main questions is if consciousness serves an independent function or is a mere side-effect of physical processes (Gutfreund, 2018). There have been interesting attempts to demonstrate the principal embeddedness of consciousness in the structure or reality, down to the quantum level (Hameroff and Penrose, 2014; Torday, 2018; Torday and Miller, 2018). “Where does the mind stop and the rest of the world begin?” was a question raised in the examination of the concept of “extended mind” (Clark and Chalmers, 1998), and since then it has been comprehensively reviewed and elaborated (Gallagher, 2018). However, Northoff (2018) questioned the very need of the concept of the mind from a neuroscience perspective and argued for shifting the focus of studies to the world-brain relations that comprehends the concept of embodiment. Besides some metaphysical issues mentioned below, I agree with the suggested ontology and epistemology of the ontic structural realism. Furthermore, I believe that the current study’s conceptualization of subjective reality facilitates a more direct consideration of the world-brain and brain-world ontological alignment.

In the quest to link subjective and objective perspectives, it is impossible to separate the investigation of subjective reality from the natural history of the species. In neuroscience, many discoveries were made using the comparative approach: the neural mechanisms underlying action potential generation were pioneered by studying the squids, experiments on aplysia contributed to understanding the neurobiology of learning and memory, the neural components of spatial representation were explored on rats (Yartsev, 2017). Perhaps the most intriguing aspect in studying the complicated forms of subjective reality is the varying nature of neural development during ontogenesis that depends on the level of parental support observed in humans and other species (Gopnik et al., 2020). Therefore, one can expect the best results regarding consciousness from inter-species comparative studies (Feinberg and Mallatt, 2019; Fregnac, 2017) that investigate an organism’s entire body (Clark and Chalmers, 1998; Segal and Clark, 2019), while focusing on cultural diversity and the corresponding neural system specifications (Han, 2017; Han and Northoff, 2008; He et al., 2021; Luo et al., 2021; Qu et al., 2021; Zhou et al., 2020), and essential inseparability between subjective reality and environment (Kohan et al., 2021; Yeshurun et al., 2021). Such an approach allows us to obtain an “understanding of the link between brain and behaviour that goes beyond causality claims” (Krahmer et al., 2017).

2. Adaptive value of human consciousness

The evolutionary history of humans provides the best-known example of how complicated subjective reality enhances the fitness of a species. Significantly, this human trait is not inherited; therefore, one must be incorporated in the caregiving society to realise the given opportunities of the organism’s structure (Gopnik et al., 2020; Hrdy and Burkart, 2020; Snell-Rood and Snell-Rood, 2020; Tomasello, 2020; Uomini et al., 2020). Availability of material and social resources in childhood may positively or negatively influence the development of the neural system, affect protracted brain development in light of the functional network segregation, which may shape cognition during adulthood (Tooley et al., 2021). The ability to control behaviour in a prosocial nature is one of the first skills in human infants (Schmidt et al., 2019). A comprehensive set of cognitive tests performed on 2.5-year-old human infants and two of humans’ closest primate relatives, chimpanzees and orangutans, demonstrated that the social skills of humans outperformed those of apes, while the ability to deal with the physical world remained comparable (Herrmann et al., 2007). This was also investigated in 2- to 4-year-old human children and chimpanzees and bonobos in the same age range, demonstrating that physical cognition was comparable at 2 years of age; further, human skills improved, while those of apes stayed the same. Human children outperformed apes in terms of social cognition at 2 years, and this difference increased further with age. Therefore, it was inferred that the development of humans and apes differs more in terms of social cognition than in terms of physical cognition (Wobber et al., 2014).

2.1. Cooperation and individuality

Although several species can form large cooperative systems, the behaviour of individual organisms is predetermined by a colony or swarm (Lyon et al., 2021; Pusceddu et al., 2021). A flora of bacteria can form a fruiting body to survive amidst lack of nutrition and perform kin-based discrimination among other colonies (Wielgosz et al., 2019); similarly, a swarm of bees or ants can be considered a multicellular organism, with spatially separated parts which preserve the distinction between germ-line and soma particles that become obvious in the asymmetry of their ageing patterns (Pen and Flatt, 2021). These species form a united body that is subject to an evolutionary experience as a whole; hence, it does not represent the “society” in a strict sense. In nature, increasing individuality of the organism’s behaviour leads to decreased group size (Read, 2005; Roberts and Roberts, 2020). Among social organisms with various individual behaviours, the group size of living chimpanzees is approximately 40, whereas it is estimated that Homo Erectus and Neanderthals could maintain a group size of 90 and 120, respectively (Dunbar, 2020a; Pearce et al., 2013). The human ability to maintain up to approximately 150 direct social connections (Dunbar, 2020a) was recently criticized (Lindenfors et al., 2021). However, authors suggested a “fractal” system of organizing primate species in a fractal series with a scaling ratio of ~3, so that human collectives fall in a ratio of 50, 150, 500, 1500… individuals (Dunbar, 2020b; Dunbar and Shultz, 2021). Therefore, human ability for long-term cooperation definitely surpasses that of other competitive species. Accordingly, living in complexly bonded social groups might provide a decisive advantage in natural selection and be among the main factors linked to complicated behaviour, contributing to the evolution of the neural system and cognitive functions in modern humans that is known as the “social brain hypothesis” (Dunbar, 2003, 2020b; Dunbar and Shultz,
2.2. Natural and social selection

Foremost, it is critical that sociality does not discard the role of the environment, but rather introduces new strategies to solve ecological problems (Dunbar, 2003; Read, 2005; Tomasello, 2020). It has been proposed that environmental instability and rapid changes in the foraging area could be among the challenges that required advanced social structure in early humans. This complicated behaviour requires better cognitive abilities and corresponding neural structures, indicating a longer period of caregiving and the necessity of cooperative care for the survival of offspring (Anton et al., 2014). Since the period of immaturity increased significantly, the survival of juveniles became dependent on alloparent care, which indicated competition and social selection of juveniles who could align with the adults most effectively (Uomini et al., 2020). The latter could have developed the ability to share intentionality and comprehend others’ subjective states; subsequently, this was transferred from juveniles to adults, thus favouring cooperation and survival in humans (Tomasello, 2020). These are elaborations of pair-bonding strategies, which include establishing intense relations with individuals of the same sex in primates; these relations are shared mostly between reproductive mates in non-primates. Two evolutionary mechanisms for its origination have been suggested: first, a necessity to carefully select a mating partner; and second, a necessity for behavioural synchrony during rearing (Dunbar and Shultz, 2007). Both mechanisms assume rearing to be time and energy consuming, and, in humans, the necessity of alloparent care could significantly enhance the requirement for cognitive abilities (Hrdy and Burkart, 2020).

2.3. Origination of culture

The moment humans developed a modern sense of subjective reality can be associated with the origination of burials with funerary attributes. Although other species can perform mortuary activities, only humans practice funerary behaviours that incorporate the dead into the structure of the group for a long period of time (Pettitt, 2011, 2018; Pettitt and Anderson, 2020). This introduces historicity over and above the life of any individual. This is important for binding the group together as well as generating and sustaining knowledge and culture. Furthermore, the second stable trait linked to the emergence of modern consciousness is stable inter-group communication. It has been suggested that migration can significantly increase the variety inherent to a foraging area could be among the challenges that required advanced social structure in early humans. This complicated behaviour requires better cognitive abilities and corresponding neural structures, indicating a longer period of caregiving and the necessity of cooperative care for the survival of offspring (Anton et al., 2014). Since the period of immaturity increased significantly, the survival of juveniles became dependent on alloparent care, which indicated competition and social selection of juveniles who could align with the adults most effectively (Uomini et al., 2020). The latter could have developed the ability to share intentionality and comprehend others’ subjective states; subsequently, this was transferred from juveniles to adults, thus favouring cooperation and survival in humans (Tomasello, 2020). These are elaborations of pair-bonding strategies, which include establishing intense relations with individuals of the same sex in primates; these relations are shared mostly between reproductive mates in non-primates. Two evolutionary mechanisms for its origination have been suggested: first, a necessity to carefully select a mating partner; and second, a necessity for behavioural synchrony during rearing (Dunbar and Shultz, 2007). Both mechanisms assume rearing to be time and energy consuming, and, in humans, the necessity of alloparent care could significantly enhance the requirement for cognitive abilities (Hrdy and Burkart, 2020).

2.4. Criticality of the group size

One may assume that the origination of culture is a distinctive trait of the modern humans; however, recent evidence has demonstrated that the cultural level of Neanderthals, the other evolutionary line of early humans, was approximately the same as the anatomically modern ones (Appenzeller, 2013; Bello, 2021; Hoffmann et al., 2018; Will, 2020). Recent experiments on brain organoids within Neanderthal genes demonstrated significant differences in neural network functions, with functional consequences for the evolution of Neanderthals and modern humans (Trullillo et al., 2021). These differences in neural functioning can affect cognitive skills and explain the smaller size of Neanderthal groups than those of modern humans, as was previously suggested (Dunbar, 2003; Pearce et al., 2013). Unfortunately, the difference in group size caused mis-adaptation in the former. The modelling demonstrated that the Allee effect—a decline in individual fitness at a low population size or density—could have led to the waning of Neanderthals, exacerbated by other ecological challenges which accelerated their extinction (Vaesen et al., 2019). Most likely, modern humans could better adapt to environmental variability by introducing mechanisms of demographic stochasticity over the course of the evolutionary development of the species (Shennan and Sear, 2021).

However, the bigger the group, the harder it is to preserve coherence within it since each individual must coordinate their own intentions with the tendencies of the society (Dunbar and Shultz, 2007, 2021; Read, 2005; Roberts and Roberts, 2020). Stress overload on each individual could facilitate the origination and development of funerary behaviour (Pettitt, 2018), music, dance, mystical stance, and other cultural practices to decrease stress and consolidate a group (Dunbar, 2020a). This has to constitute a self-reinforcing feedback loop with the modification of the caregiving strategy, which results in the origination of “theory of mind”: to receive required alloparent support, juveniles learn to emotionally align with adults by engaging in cooperative activities; those who master this ability to cooperate with peers become adults (Hrdy and Burkart, 2020; Tomasello, 2020; Tomasello and Vaish, 2013; Uomini et al., 2020). Fig. 1 presents the expected steps of behaviour and neural system’s alignment in the face of environmental and social challenges.

Therefore, modern humans faced the necessity to preserve social cohesions more than any other kin species; this became the most important drive in the evolution of the brain (Dunbar and Shultz, 2007; Tomasello and Vaish, 2013). This socio-ecological requirement does not manifest only in the form of taboo and penalties but also in the form of creating extra-safe havens for juveniles (Uomini et al., 2020). Other forms of promotive social selection have similar effects, whereby they significantly decrease the capability of sole survival, whereas the lack of required parental support alters the neural development to increase future independence (Snell-Rood and Snell-Rood, 2020; Tooley et al., 2021). To incorporate an individual into a society, culture supplies a complicated system of awards and punishments. The coevolution of socio-ecological requirements, cultural practices, and cognitive abilities caused the origination of human consciousness as the most complicated form of subjective reality among the known species. Furthermore, human evolutionary history demonstrates that subjective reality is an effective cause of behaviour and justifies its ontological reality. Nevertheless, this statement can still be argued from an illusionism perspective (Dennett, 2018; Frankish, 2017). Therefore, a scientific explanation of the interaction between subjective reality and neural systems is required. Next, the most well-elaborated theories of consciousness will be reviewed.
3. Theories of consciousness and the concept of subjective reality

Preserving social cohesion in everyday life is possible when the cultural norms complement some natural instincts and surpass others. Since the knowledge of these norms cannot be an inherited trait, they must be acquired through learning and incorporated into one’s subjective reality to become the cause of an instant action. One’s functional ability to operate information during an activity is considered working memory (Christophel et al., 2017; Hasson et al., 2015; Velichkovsky, 2017). It has been proposed that the enhancement of working memory capacity could be a reason for the origination of culture (Balter, 2010; Carruthers, 2013). The significant shift in crafting skills is associated with the origination of highly symmetrical hand axes that probably required constraining an image of the desired tool in mind while handling the material; the same cognitive ability is critically important for the prediction of the future (Balter, 2010). The latter could be a decisive factor in reaching the contemporary size of human groups following the discussed evolutionary mechanisms. However, the above studies have mostly focused on the operational capacity for effortful activity during the creation of cultural artefacts since it implies reportability, considered a main trait of the human consciousness. Nevertheless, there is a certain amount of discussion on the extent to which one has cognitive access to the content of one’s subjective experience (Gross, 2018; Nakano and Ishihara, 2020).

3.1. Non-conscious computations and the sense of confidence

One of the most influential explanations of the subjective experience suggests that consciousness originates when many non-conscious domain computations are combined in a global neuronal workspace, thus making regional information available globally (Baars and Franklin, 2003; Changeux et al., 2021; Dehaene et al., 2017). Therefore, the neural system can simultaneously run multiple automated processes, which compete and cooperate to deal with an organism’s instant goal. Merging these possesses results in an intrinsic feeling of (un)certainty (Dehaene, 2018) that monitors the coherence of conscious events with unconscious perceptions (Shea and Frith, 2019); therefore, executive functions have potential access to much more information than one may be aware of in that instant; this represents an adaptive advantage. Considering the conscious experience as a direct result of non-conscious computations (Dehaene et al., 2017) assumes the presence of specific underlying mechanisms that integrate the broadcasted content. Along with the criticality of inter-domain connectivity, this may require executive functions that are strongly associated with the prefrontal cortex (Barbosa et al., 2020; Carlen, 2017; Raichle, 2015). The global workspace theory expects this region to be one of the primary mechanisms involved in broadcasting information across the neural system. However, there is evidence that the prefrontal cortex is vital for manipulating and metacognition (Christophel et al., 2017), but not for the maintenance of information in working memory (Hasson et al., 2015; Manciscalco and Lau, 2015; Nakano and Ishihara, 2020). Despite controversial issues, it is clear that environmental interaction involves the activation of various neural areas (Changeux et al., 2021); therefore, working memory is distributed in activity-salient mechanisms across the neural system, particularly, in the sensory, parietal, and prefrontal cortices (Christophel et al., 2017; Hasson et al., 2015). Since working memory is represented as a whole neural network and results in a
behavioural response, localization of the neural activity is highly task-dependent, so that the design of the experiment predetermines its outcome in many aspects. Thus, it was suggested that one must focus on unravelling the reaction of the whole neural system to the environmental effect and produce an appropriate behaviour (Christophel et al., 2017). This problem is interrelated with the task of distinguishing the prerequisites and consequences of the conscious processes (Aru et al., 2012). Therefore, it is highly likely that considering reportability as a distinctive trait of conscious events (Baars and Franklin, 2003) predetermines the focus on relatively higher-order executive functions and integrates it into the experimental design of the brain structures that are responsible for conceptualisation (Aru et al., 2012). Although meta-cognition may not be explicit, but embedded in a global workspace as a characteristic of combining different computational streams that results in a sense of confidence (Shea and Frith, 2019) or (uncertainty (Dehaene, 2018), this theoretical explanation still considers subjective experience as a mechanistic response to the environmental activity. However, maintaining life involves an adaptive environmental interaction, meaning that even the simplest organisms demonstrate some forms of basal cognition, among which the most important can be hierarchical structures of mechanisms, controlling their own productive functions (Lyon et al., 2021). Such a control over one’s own behaviour assumes creating and supporting internal models of the environment that possess a real causative power and actively interact with the surrounding world (Bechtel and Bich, 2021). This is impossible without reafference—knowledge about own internal states—which can be conceptualised as a “proto-self” that distinguishes an organism from its environment (Jekely et al., 2021).

Furthermore, many animals, such as songbirds, octopi, and bats, can learn and demonstrate creative behaviours (Boly et al., 2013; Feinberg and Mallatt, 2019; Yartsev, 2017), which points to the significant role of subjective experience and the accumulation thereof. Many animals, such as meerkats, cowbirds, and even rock ants, can modify their behaviour to teach juveniles (Gurven et al., 2020); there are debates on whether other species, especially songbirds and apes, can utilise syntax in their communication, and the extent to which the cognition in animals exceeds their abilities to share acquired knowledge (Fishbein et al., 2020) to report their subjective states. Therefore, linking consciousness together with the complicated executive functions and the associated neural structures may be effective in studying species with a relatively complicated subjective reality, but it inevitably neglects simpler forms and evolutionary predecessors.

Besides the global workspace theory discussed above, there have been many attempts made to explain the origin of subjective experience from non-conscious neuronal computations. The suggested mechanisms vary—these can consist of the recursive application of schemes of the perceptual description to the own process of attention (Graziano et al., 2019) or the higher-order operations with the first order processes or symbols (Rolls, 2020; Rosenthal, 2020). These integrate non-conscious processes in a reportable and consistent manner; they provide “minimal inner awareness of one’s ongoing mental functioning” (Brown et al., 2019). However, these theories mostly assume that there is a universal structure of cognitive processing in all humans or even all living organisms. Nevertheless, there are strong arguments supporting the significant differences in the neural system and subjective reality. Sexual dimorphism was observed in the brain structures of primates; they centred on conflicts in males and favoured socio-cognitive skills in females (Linden et al, 2007), while the later 2018 study still reveals increasing differences in naturalistic behaviours between the sexes, which warrants the modification of the neuroscience research paradigm and approaches (Shanksy and Murphy, 2021). This specialisation of the neural system implies significant differences in cognitive strategies, including self-awareness and perceptual description of the surrounding.

Further, there is strong evidence that culture and environmental background influence one’s behaviour, neural structures, and cognition (Han et al., 2013; Luo et al., 2021). Neuroimaging demonstrated significant differences in neural substrates of self-representation and self-awareness. One of the pioneer studies, performed on East Asian and Western participants, showed that the concept of “mother” was associated with Self in the former and with others in the latter (Han and Northoff, 2008). The recent studies demonstrated that both East Asians and Westerners perform an “own-race bias” facing social exclusion, while the latter were more capable of regulating associated negative emotions (He et al., 2021). Evaluating the metrics of the default mode network and subcortical areas allow to distinguish between East-Asian and Western participants with a predictive power higher than a chance level: in the former, maintaining harmonious social cohesion is associated with a crucial role of the amygdala, basal ganglia, and temporal pole, while in the latter, the gray-matter volume of default mode network regions—vmPFC, right DLPFC, and right RLFP—report a positive correlation with behavioural independence and self-agency (Qu et al., 2021). The whole human body participates in emotional expression, and it was shown that self-evaluative social emotions (pride, shame, disappointment, joy) are involved in regulating social interaction and shaped by the cultural values (von Suchodoletz and Hepach, 2021). Significantly, it is more accurate to consider social values as a subjective construct, measured with vertical and horizontal dimensions of individualism and collectivism (Singelis et al., 1995), rather than an unchangeable individual or collective pattern. These contributions justify that each “mode of thought” (Whitehead, 1938) introduces particular cognitive predispositions that are not necessarily intrinsic to any subjective reality.

3.2. Neural system’s architecture and integration

To overcome the described bias, one may try to identify the intrinsic qualities of any experience and determine how a more complicated subjective reality originates on this foundation. This approach was initiated at the beginning of the 20th century in the field of phenomenology, which suggested that, to illustrate the intrinsic structure of the subjective reality, one must avoid any judgements on the real existence of the phenomenal experience and focus on its formal structure (Husserl, 1977). However, it seems to end in a “solipsism,” in which the self is all that can be known to exist. Today, the integrated information theory incorporates the phenomenological approach, starting from the intrinsic qualities of experience but supplying it with mathematical modelling and neuroimaging (Koch, 2018; Tononi, 2008; Tononi et al., 2016; Tononi and Koch, 2015). The core idea of this theory is that if information of an integrated system surpasses the sum of the information generated by its parts, there must be subjective experience.

The integrated information originates only if it is in-built into the system’s structure and cannot be a result of mere computations; hence, even complicated feed-forward networks—such as a deterministic computer that perfectly mimics the human behaviour—have no consciousness because information of this system does not exceed the sum of information in its parts (Koch, 2018). However, the composition of self-referential mechanisms can produce such additional information, which assumes that experiencing is a fundamental property that can be inherent to any organism (Tononi and Koch, 2015). Modelling demonstrated that systems with self-referential architecture are effective, laconic, and can possess their internal states and goals. These modelling results can be used to support the inference that subjective reality originated as an optimal measure between centralised control and body part autonomy as well as between the domains of the neural system (Demertzi et al., 2019; Dubrovska; 2015; Jekely et al., 2021; Luppi et al., 2019). Such diversification of tasks allows for the integration of huge amounts of information, which enhances the fitness of the species during natural selection (Popiel et al., 2020). Empirical studies on the human brain reported the contribution of integrated information theory in allocating the subjective reality to non-responsive patients (Koch, 2018). Moreover, it significantly predicts that overall connections among elements of the neural system—that is, the architecture of the whole
system—can contribute to the formation of the experience even when some areas are inactive (Tononi et al., 2016). This thesis also emphasizes global connectivity, and one may consider it to be quite similar to the global workspace theory discussed above. However, the latter assumes that only actual neuronal activity of different genesis can contribute to the synthesis of non-conscious computation streams into the subjective experience with an inner sense of confidence (but see (Changeux et al., 2021)). Conversely, emphasizing system architecture in the integrated information theory contributes to considering neuronal system as a stochastic unity that will be discussed below.

The suggested models reveal the importance of integrated architecture (Tononi et al., 2016) and justify the critical significance of global connectivity in the origination of consciousness (Aru et al., 2020; Dehaene et al., 2017); however, they still consider subjective reality resulting from the activity of a limited set of mechanisms. The complexity and diversity of the human neural system (Deweerdt, 2019) may put into question the very possibility of implementing this method to create a wholistic brain image (Abbott, 2020). However, the most important obstacle is not the lack of computational capabilities, which can be overcome (Abbott, 2021), but the very approach to identify the physical correlates of consciousness with causal mechanisms (Frégac, 2017). Penrose (1989) criticised the consideration of consciousness as a deterministic system and further supported the orchestrated reduction theory (Hameroff and Penrose, 2014). This theory assumes that intrinsic indeterminacy is a distinctive trait of consciousness, which originates from sub-neuronal quantum information processing in the brain microtubules. The mechanisms suggested were extensively criticised, and a decisive experiment was recently proposed by Hameroff (2021). I believe in the accuracy of the general intention of this theory to demonstrate that subjective reality is an intrinsic property of the physical reality; furthermore, considering processing on “superposition of possibilities,” a foundational function of consciousness, is highly worthy of attention. However, this theory dilutes the emergence of the experience, awareness, and consciousness to the sub-neuronal quantum level of the matter organisation, while the composition of neuronal mechanisms seems to remain deterministic. In this case, the uncertainty of basic processing can supply randomness to the behaviour but cannot explain both free will and conscious choice.

3.3. Active interaction with the world

Evaluating consciousness at the micro-level is misleading because subjective reality is not a mathematical abstraction that requires proof of indeterminacy, but, rather, a tool for a particular task to enhance an organism’s fitness (Feinberg and Mallatt, 2019; Jekely et al., 2021; Lyon et al., 2021); survival does not correspond to solving a theorem in a predetermined circumstance. Evolutionary effectiveness of human consciousness discussed above also justifies that the prerequisite of subjective reality is adapting to natural and social regularities in a “manipulable environment” (Clark and Chalmers, 1998). Thus, the uncertain conditions of the environment are much better represented in a probabilistic model than in a limited set of strictly predetermined reactions to stimuli (Boly et al., 2013; Hari et al., 2015). The recently anticipated learning machines utilise non-linear evolution of higher dimensional data and produce better results in predicting unexperienced events than the traditional statistics-based machine learning (Chen et al., 2020).

To elaborate on such an approach, it is critical that the neural system is not a passive conglomerate of deterministic mechanisms that can only react to the inputs from the environment. In psychology, Gibson pioneered the consideration of perception as a active process of extracting invariants of form from the surrounding environment (Gibson, 1979), which inherits the philosophy of Kant (1781/1991). Currently, there is clear evidence that no passive representation of independent items in objective space and time exists; however, the construction of relationships between the events of perception is apparent (Buzsáki and Llinás, 2017; Hari et al., 2015; Northoff et al., 2020; Pezzulo et al., 2021). Importantly, neural hypersynchrony may lead to the loss of consciousness (Boly et al., 2013), whereas preservation of the conscious state relies on the anticonnected dynamics of self-monitoring and interactions with the environment (Huang et al., 2020; Raichle, 2015). Therefore, the philosophical challenge of solipsism (Husserl, 1977) makes sense only in cases of neural lesions (Boly et al., 2013; Demertzi et al., 2019) or possible “islands of awareness” (Bayne et al., 2020).

These advancements allow one to infer that the prior task of subjective reality is to align it with an uncertain environment (Boly et al., 2013; Pezzulo et al., 2021; Segal and Clark, 2019). Chapters 3,6, and 8 in a recent study by Northoff (2018) comprehensively argue that the brain exists only within world-brain relations. This framework also supported by a mathematical explanation regarding the energy efficiency of the neural system due to its own intrinsic stochasticity (Palmer, 2020; Popiel et al., 2020), the concept of the “thermodynamics of thinking” (Buxton, 2021), advances in non-invasive neuroimaging (Barron et al., 2021), transcranial therapy (Iimori et al., 2019), inter-subject functional correlation analysis (Yeshurun et al., 2021), and understanding Self in the context (Roban et al., 2021).

3.4. Neural system’s stochasticity and subjective experience therefor

An active interaction with the environment is possible if the neural system constantly performs intrinsic default or resting activities (Demertzi et al., 2019; Huang et al., 2020; Luppi et al., 2019; Northoff, 2018; Pezzulo et al., 2021; Raichle, 2015; Yeshurun et al., 2021). The non-conscious states involve highly predictable dynamics that mostly follow anatomical connectivity of the brain regions, in which a low interareal phase coherence mainly is mediated by structural connectivity, and there are little chances of changing the patterns of the neuronal activity. In contrast, the conscious state produces much more complex spatiotemporal patterns of inter-domain connectivity; thus, it was suggested that preserving conscious states requires the sustenance of diversified brain dynamics (Demertzi et al., 2019; Huang et al., 2020; Luppi et al., 2019). To be integrated into a system and subsequently perceived, any stimulus must be allowed within the intrinsic activity of this organism. However, the stimulus also has to match the rhythm of attention (Lakatos et al., 2008) or a hierarchical pattern of “temporal receptive windows” (from short to long scales), incorporating the extrinsic stimuli within the intrinsic temporal organisation of the brain’s neural activity (Hasson et al., 2015; Northoff and Huang, 2017). A recent study put forth a well-structured explanation of the neural system’s intrinsic activity as a top-down generative model used for learning and adapting to the environment: in a context-independent manner it prepares the brain to respond to a wider range of stimuli by optimizing generative models for future interactions, thus, maximizing the entropy of explanations (Pezzulo et al., 2021).

A concept of “spontaneous brain” was introduced to summarize arguments suggesting that the neural system is not deterministically reactive, but incorporated in world-brain relations and can only exist accordingly (Northoff, 2018). It assumes that the overlap between intrinsic and stimulated neural activities is self-specific and constitutes its own time and space in the subjective experience (Northoff, 2018; Northoff and Huang, 2017; Northoff and Lamme, 2020; Northoff et al., 2020; Wölf et al., 2019). Intrinsic activity provides “temporal nestedness” for the stimuli, and the consequent overlap determines the state of the neural system as a whole. Any conscious or non-conscious perception modifies the current neural dynamics, which is the nesting predisposition for the subsequent event. To emphasize tempo-spatial dynamics of the neural system as a predisposition and prerequisite of consciousness, a concept of “spatiotemporal neuroscience” was suggested (Northoff et al., 2020).

Additionally, behavioural reactions in the conscious state are not unambiguously predetermined at the neuronal level, but, depending on the context, may lead to several possible behavioural outcomes; thus,
the whole organism’s dynamics matter (Frégnač, 2017; Koban et al., 2021). The most recent studies demonstrate striking advances in the classifying patterns of brain-to-brain synchrony during naturalistic interactions (Yeshurun et al., 2021). Therefore, one may assume a correlation between the richness of subjective reality, reported in one’s first-person experience, and the stochastic dynamics of their neural system, subject to third-person imaging. Measuring entropy of the neural system to allocate the presence of consciousness is already a well-established practice (Alu et al., 2020; Burioka et al., 2005; Carhart-Harris et al., 2014; Pezzulo et al., 2021). Besides controversial issues and differences in the methods, one may assert that the neural state entropy is significantly reduced in all unresponsive conditions, which are less uniform, imbalanced, and therefore more stereotypical than conscious states (Huang et al., 2020). As presented in Fig. 4.2, a “spectrum model” of the brain in relation to the levels of consciousness was conceptualized by Northoff (2018). Further, it was emphasised that consciousness is present at average and vanishes at the extreme values of the neural system functioning (Northoff and Tumati, 2019). To demonstrate the interdependence of neural system’s entropy and with different levels/states of consciousness, vast empirical data were summarized in Fig. 2a. by Northoff et al. (2020). Considering all the above-mentioned and suggested studies and that “entropy is a measure of signal predictability and quantifies the degree of the disorder of a system and the complexity of dynamic changes” (Alu et al., 2020), I estimate that entropy degrees of the neural system and the subjective reality are inversely dependent. Low degrees of the neural system’s entropy (characterized with more stereotypic and predictable patterns of brain connectivity) predetermine non-conscious states, while high degrees (characterized with more rich and unpredicted dynamics) are associated with conscious awareness, but may cause loss of the adequate interaction with the surrounding world after reaching criticality. Fig. 2 represents this model in a graphical form, and its limitations are discussed below.

4. Neural system, culture, and the ability to be conscious

Highlighting the stochastic dynamics of the neural system in the origination of experience is coherent with recent studies on working memory which demonstrated that working memory is not limited to a fixed number of information chunks but is flexibly distributed between tasks (Hasson et al., 2015; Ma et al., 2014). It has been suggested that the limited capacity of working memory is a trade-off for its flexibility and originates from the interference between the operated items (Almeida et al., 2015; Bouchacourt and Buschman, 2019).

The application of this model to a neural system implies that the interaction of the default activity with a single stimulation produces an easily distinguishable interference pattern that almost unambiguously results in the particular behaviour (Christophel et al., 2017). Enhancing the uncertainty of a signal or quantity of simultaneous perceptions increases entropy, causes working memory “overflow,” and harms the preciousness of the reaction (Maniscalco and Lau, 2015). This explains the interrelation of cognitive sensitivity and load of attention; this implies that one has cognitive access to the whole broadcasted working memory (Gross, 2018; Hasson et al., 2015) although one may be unable to conceptualise and report its full content (Aru et al., 2012; Maniscalco and Lau, 2015). Therefore, extracting information from the interference patterns depends on the current circumstances (Northoff and Huang, 2017; Northoff et al., 2020; Yeshurun et al., 2021).

4.1. Continuity of the subjective experience

Real experience does not consist of separate perceptions (Gibson, 1979), but recent memories usually affect the actual data (Hasson et al., 2015; Yeshurun et al., 2021), which may cause bias in the behavioural output (Barbosa et al., 2020). In rats, silencing of the brain area that represents recent history can improve overall task performance, especially when dealing with irregular stimulation (Busse, 2018). Moreover, by thinking of some past event, we tend to not deal with the conceptualised proposition, but rather recollect a whole situation which contains rich experiential details (Buszaki and Llinás, 2017). This can even be described as travelling into the past (Mahr and Csibra, 2018), and the reactivation of a correspondent neural trace of a past event is necessary to achieve this subjective experience (Schreiner and Staudigl, 2020). These advances in studying mechanisms of memory invoked a shift from looking at the “systems of memory” to the “memory of systems” (Hasson et al., 2015), while assuming that even a slight alteration in the reactivated components will cause a significant change in the whole composition and alter the experience. Therefore, memories do not require storing all the richness of the experienced data (as it happens in modern computer technology) but can be encoded as a pattern of connectivity between neural domains, whose simultaneous activation supplies the required feelings to re-experience the memorised state. Further, a neuroscientific explanation of perception based on the difference-based coding model is argued by Northoff (2018); this is the statistically significant difference in the environment that is encoded in the neuronal activity. These mechanisms can explain the outstanding capacity of long-term memory and illuminate why awareness of the present is preserved while recollecting past experiences in a conscious state (Mahr and Csibra, 2018). Thus, the complete immersion in the past is rare: the ongoing neuronal dynamics still alter the reactivated pattern of the memorised state. Based on these theories and evidence, it is possible to explain the mechanics of offline perceptions and spontaneous experience (Fazekas et al., 2021), false recollections, and déjà vu. The
offline perceptions seem to be associated with the spontaneous activation of the domain systems, when it is sufficient for producing a pattern associated with perception. The déjà vu may originate with the current interference patterns of the working memory, interlaced with the components of the previous perceptions, because of the slight differences in their component neuronal processes. An additional argument for the unceasing continuity of the subjective experience comes from the studies of lucid (consciousness) dreaming, which includes some features of normal awareness, such as preserving activity of anterior prefrontal, parietal, and temporal cortex (Baird et al., 2019; Boly et al., 2013). In addition, a possibility of the two-way communication with individuals during rapid eye movement sleep was demonstrated: participants could perceive questions from an experimenter and use eye movements and facial muscle contractions to give answers, many of which were correct (Konkoly et al., 2021). This demonstrates that subjective experience is not a black-and-white dichotomy of non-conscious and conscious states, but it possesses a multi-level gradation of awareness, the form and the content thereof directly represents the current state of the neural system—as shown in the Fig. 2.

4.2. Neural activity interference forms the subjective reality

Summarizing that preserving consciousness requires an active interaction with the environment, purposeful activity necessarily utilize resources of the working memory that may be limited because of the interference between the computational streams, and tempo-spatial wave dynamics of the neural system (Northoff, 2018; Northoff and Huang, 2017; Northoff et al., 2020; Yeshurun et al., 2021), it is possible to identify a moment of experience with a corresponding interference pattern of overlap between the default and stimulated neural activities. The general inference is that one’s subjective experience is a direct representation of their neural dynamics as a whole. This hypothesis may unite the stochasticity of the subjective reality and neural system in a set of corresponding wave functions, and possibly enable the consideration of the temporal dimension of subjective reality as a probability of having a particular experience associated with the particular interference pattern of neural dynamics. Therefore, one’s qualitative feelings may be represented through quantitative assessments of modifications in the nesting neuronal activity after the environmental effect. Fig. 3 demonstrates suggested conceptualization in a graphical form.

The wave nature of neural activity determines that its overlap results in an interference pattern cannot be reduced to a sum of its sources; therefore, it must contain information over and above the sum of information produced by the domain systems. The latter is critical in the origin of intrinsic subjectivity in the context of the integrated information theory (Koch, 2018; Tononi et al., 2016). The electromagnetic nature of neuronal functioning assumes that the neural system as a whole constitutes firing of neural ensemble and given that it involves wave dynamics that can affect the functions of the large neural areas, and not a mechanistic causation that is limited to the direct connectivity between neurons. Therefore, it can provide inter-domain connectivity, required for the origination of consciousness in the global workspace theory (Dehaene et al., 2017; Demertzi et al., 2019), representing the highest hierarchical level of the neural system’s organisation (Changeux et al., 2021), and contribute to a holistic approach in considering partially independent neuronal system in a principal unity with the world (Alu et al., 2020; Northoff, 2018; Northoff et al., 2020). Thus, the suggested theoretical explanation of the subjective experience as a direct representation of the neural system’s stochasticity embraces the most well-elaborated theories of consciousness discussed above. Furthermore, if, at least in some cases, global connectivity utilises wave interference caused by the activation of the neural domain system, then the lack of direct neuronal connections does not imply the absence of integration between domains. Therefore, under uncertain conditions, the general state of the neuronal system that results in the form of subjective experience can be affected by ancillary processes, which are not included in the current pattern of neuronal spatial connectivity in the form of direct cell-to-cell connections. This can explain an outstanding case of patients with split-brain, which can preserve the unity of their experiences and shared working memory (Volz and Gazzaniga, 2017): If subjective experience and functioning of the working memory depends on the wave interference emerged from the neuronal activity, it can partly compensate the absence of direct neuronal connectivity in corpus callosum between the two cerebral hemispheres.

4.3. Basal role of social interactions for emerging of the human consciousness

The accumulation of individual experience is vital for humans who must meet the requirement of both natural and social environments. Coordinating individual behaviour with the socio-ecological requirements starts early in childhood (Herrmann et al., 2007; Schmidt et al., 2019; Tomasello, 2020; Wobber et al., 2014) and imprints on the brain (Han and Northoff, 2008; He et al., 2021; Markova et al., 2019;...
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Snell-Rood and Snell-Rood, 2020; Tooley et al., 2021; von Suchodoletz and Hepach, 2021). A flexible human society implies that learning social norms during initiative socialisation is insufficient. To preserve the required social cohesion, one needs their intentions to be consistent with society (Dunbar, 2003, 2020a; Hari et al., 2015; Roberts and Roberts, 2020). When achieving the principal ability to control intentions, individuals are then responsible for these actions, which are why, in most cultures, children and adults with evident lesions of cognition are not subject to legal responsibility for their actions.

An innovative study demonstrated that self-control is a resource-consuming task because both state and trait self-control capacity can be predicted by an interplay of working memory and action-state orientation (Groß and Kohlmann, 2020). Thus, no one will control their behaviour if there is no objective need for this. The requirement to strictly preserve the social cohesion and evolutionary selection of children who are best aligned with adults is linked to the origination of specific cognitive mechanisms to obtain competitive advantages in seeking alloparen care (Hrdy and Burkart, 2020). However, emotional alignment with adults in cooperative activities must be supplemented with behaviours that are normative in society and constitute its “morality” (Tomasello and Vaish, 2013). Eventually, one learns to evaluate one’s own actions from the third-person point of view, interiorise the cultural norms of behaviour, and identify oneself based on the apprehension by the society, in the form of one’s “self” (Harré, 1984; Prinz, 2018). The mechanisms for diversifying oneself from the environment may be among the most basic abilities of each organism (Jékely et al., 2021), while particular strategies of self-reporting in humans are well described in higher-order thought theories (Brown et al., 2019; Rolls, 2020; Rosenthal, 2020). After the constitution, the “self” is incorporated in one’s subjective reality; it provides instant access to the acquired social norms in the form of self-identification with perceived social roles.

4.4. Human consciousness must be mastered during the life

The significant correlation between self-control and working memory load (Groß and Kohlmann, 2020) favours the suggested explanation of the conscious process involving the preservation of the orderliness of the system that is fully subject to the thermodynamic explanation of the brain’s cellular processes (Buxton, 2021). In summary, human consciousness requires two critical predispositions. The first is the functional ability of the neural system to perform goal-directed behaviour (Carlen, 2017), while simultaneously constraining the outcome and

Fig. 4. Theories and advances in studying consciousness synthesized in the concepts of the subjective reality and human consciousness. Global workspace, integrated information, and spatio-temporal theories of consciousness propose that an ability to have a subjective experience can emerge in an interconnected and integrated system, which intrinsic activity modifies incoming stimulation from the environment and results in patterns of spatiotemporal dynamics that can be associated with the particular forms of subjective reality and consciousness.
social requirements such that the capacity of working memory must revolve around four information chunks (Ma et al., 2014). This consists of a methodical distinction which is amenable to studying naturalistic behaviour, while working memory is incorporated in the processing neural structure (Bouchacourt and Buschman, 2019; Hasson et al., 2015; Velichkovsky, 2017). Goal-directed behaviour requires at least two information chunks to monitor the actual situation and constraining the object of the intention. Life experience supplies the ability to predict its consequences, which must be weighed against the possible reaction from society – as such, indeed, these require two additional chunks of working memory, at least while making a conscious choice. Consequently, one can conceptualize their behaviour and reach a perception of “self.” The second predisposition is the socio-ecological necessity to preserve consistent social cohesion, which introduces the reason for mastering consciousness in the life of each individual. An evolutionary logic of this process was conceptualized in Fig. 1.

Different cultures have found various methods to incorporate juveniles into their society, which implies differences in their cognition (Han, 2017; Han et al., 2015; Han and Northoff, 2008; He et al., 2021; Yeshurun et al., 2021; Zhou et al., 2020) and invokes dissimilar modes of thought (Whitehead, 1938). Since being conscious consists of the skill to conceptualize the inherent power dominating one’s action, cultural and sex diversity is the critical predisposition for the release of arts and science, which are significantly linked to the further evolution of the human species.

5. Summary and conclusion

Synthesizing the reviewed theories of consciousness propose that the stochastic dynamics of an organism’s control system are experienced in the form of subjective reality. It predicts that any organism that can run a default activity, which overlaps with the stimulated activity causes an interference pattern, interacts with the environment in the form of subjective reality. Thus, subjective reality is not an emerging function that can be separated from an organism, but rather a way in which the process of life is experienced by the organism itself.

In evolutionary development, humans’ greater dependence on preserving social cohesion for survival necessitated greater demands on working memory, which is critical for preserving social norms. The subjective reality may be solely responsible for human behaviour, which has evolutionary advantages and diversifies cultures to maintain social cohesion. Preservation of cultural norms warrants mastering the skill of behavioural control at the level of the intentions—that is the conscious in a human sense. Therefore, I propose to define “subjective reality” as a systematic trait of any organism with sufficiently complicated control systems to experience environmental interaction, and to define “consciousness” as a distinct human ability to control behaviour at the level of intentions. Fig. 4 represents suggested conceptualization.

To elaborate on the general conceptualization provided above, I suggest that the entropy of neural system and subjective reality is inversely interdependent: The higher the entropy of the neural system, the lower the entropy (uncertainty) of the subjective reality, and their grades result in a particular state of consciousness (non-responsiveness, sleep, conscious awareness, illusion); as shown in Fig. 2. Further, in Fig. 3, I sketch a two-dimensional coordinate system to describe the basic interactions between default and stimulated activities from the third- and first-person perspectives. Any perceptions can be consistent with or contradict the default mode network’s activity and other intrinsic activities, which cause feelings of pleasure or anger, respectively, both of which can integrate or disintegrate the system, and individuals experience the former as excitement and the latter as depression. Some perceptions can be consistent with or contradict the intrinsic activity, although it can increase or decrease the overall integrity in a moment of time. Therefore, pleasure and pain may compete in one’s subjective reality, but excitement and depression are exclusive states, which may still vary. This framework considers consciousness in the context of the world-brain relations and allows bridging the gap between investigating basal and higher-order forms of cognition and between natural and social sciences.

In philosophy, naturalism was both praised and criticized for the attempts to reduce consciousness to some non-conscious processes. However, the Oxford dictionary defines nature as “inherent power dominating one’s action”, while the original meaning of reduction is “going back” (Hoad, 1993). Thus, the correct natural reduction of consciousness is clarifying the origination and development of subjective reality in the evolution of a species. Despite the limitations, the aim of this review was to contribute to the naturalistic theory of consciousness freed from the intentional or unintentional bias of vulgar reductionism (Krakauer et al., 2017). I appealed to the anthropological studies of human evolution and used the concept of working memory to establish a link between the naturalistic behaviour and its neural basis. Furthermore, if my prediction that current state of the subjective reality is similar to the ongoing interference pattern emerged from the neuronal spatio-temporal dynamics is true, it suggests a direct connection and alignment of the subjective experience and consciousness with the world rather than assuming indirect mechanisms. Thus, from the ontological perspective, this framework can be classified as realism because subjective reality and consciousness are considered a real process that have their own causative power on the organism’s behaviour and the world. An assumed direct relation between the subjective reality and the world allows to mitigate clarification of the realism’ type. While, if necessary, it can be qualified as an “activity realism” (Lektorsky, 2021) or “ontic structural realism” (Northoff, 2018).

6. Ongoing research limitations

This review has several limitations. First, it could investigate only a limited number of studies because there are too many theories concerning consciousness. Some studies (Northoff, 2018; Northoff and Lamme, 2020; Schneider and Velmans, 2017) offer an in-depth investigation of the theories of consciousness. Special journal issues have been devoted to life history (Gopnik et al., 2020), offline perceptions (Fazekas et al., 2021), political brain (Zmigrod and Tskakiris, 2021), and basal cognition (Lyon et al., 2021), which are worth paying attention to.

Second, some arguments regarding the evolutionary effectiveness of subjective reality are mostly based on modelling (Palmer, 2020; Poppel et al., 2020; Tononi et al., 2016); thus this subject is open to debate from the perspectives of dualism (Chalmers, 2018) or illusionism (Dennett, 2018). However, advances in biology (Lyon et al., 2021) and anthropology (Gopnik et al., 2020), the prediction model of brain and evidences of the “spatiotemporal alignment” between brain, body, and world in neuroscience (Northoff, 2018) justify the evolutionary need for consciousness (Dubrovsky, 2019; Feinberg and Mallatt, 2019). At the same time, the research of the neural system’s spontaneous activity mostly involved participants from the West, which can cause a doubt if revealed principles are similar for the other ethnic groups. On one hand, the recent studies with the East Asian participants demonstrated the same crucial role of the neural system’s intrinsic activity; however, there are evident differences, which were discussed above (He et al., 2021; Luo et al., 2021). Future research must pay more attention to the cross-cultural and multi-ethnic aspects.

Third, the suggested combination of objective and subjective approaches (sketched in Figs. 2 and 3) is theorising that is an attempt to identify regularities in the environment (Gibson, 1979). One must be aware that since a theory has no objective existence beyond the human mind, it must prove its efficiency in practice. Particularly, considering “entropy” (uncertainty) of the subjective reality invokes a question regarding how to measure it besides relying on the self-reports of participants, which can merge prerequisites and consequences of consciousness (Aru et al., 2012), and subject to all the arguments against the report paradigms reviewed above. However, advances in empirical studies are impossible without the reconsideration of scientific
paradigms’ core ideas (Frégacq, 2017; Krakauer et al., 2017; Yartsev, 2017). The studies on extracranial stimulation (Ilimori et al., 2019; Quentin and Cohen, 2019; Reinhart and Nguyen, 2019) and inter-subject functional correlation analysis (Yeshurun et al., 2021) are most appropriate to test the theoretical framework suggested in this review. The ways to elaborate on and test the provided conceptualisation are suggested below.

7. Scope for future research

7.1. Theoretical neuroscience

In neuroimaging, the suggested approach can promote the explanation of the behavioural and neuronal synchrony observed during interpersonal coordination between spouses, in co-parenting couples, and in mother-child pairs (Azhari et al., 2020; Kinreich et al., 2017; Markova et al., 2019). The correlation of neural activities in these pairs is grounded in their subjective realities, justifying the bidirectional communication between objective and subjective states (Yeshurun et al., 2021). In the treatment of brain lesions, studies have demonstrated that the extracranial synchronisation of cerebral circuits could temporarily revive working memory in older adults (Quentin and Cohen, 2019; Reinhart and Nguyen, 2019). The suggested inverse interdependence between the neural system’s stochasticity and the orderliness of subjective reality illuminates how and why extracranial modification of the brain’s dynamics—that inevitably affect large domains of the brain (Barron et al., 2021)—have a therapeutic effect and restore a patient’s cognitive abilities to some extent (Ilimori et al., 2019). Furthermore, shifting the concept of reality using psychedelic drugs (Carhart-Harris et al., 2014) can provide important information on how alteration of the known neural processes modifies the overlapping pattern and how it affects one’s subjective experience, which can be simultaneously imaged and reported. The same applies to two-way communication with lucid dreamers (Konkoly et al., 2021).

Studying the split-brain (Alu et al., 2020; Volz and Gazzaniga, 2017) in animal models can be an easy way to test the suggested hypothesis that neural systems’ interareal connectivity (Changeux et al., 2021; Dehaene and Changeux, 2011) and integrated architecture (Alu et al., 2020; Tononi and Koch, 2015), as well as functioning of the working memory, relies on the wave interference resulting from the neural dynamics at least in some cases: Shielding the two hemispheres from each other with the present and absent corpus callosum while performing behavioural activity that requires interaction between hemispheres tested by corresponding behavioural task can prove or falsify the criticality of the wave interference for the functioning of the subjective reality and working memory capacity.

7.2. Patients’ treatment and ethical issues

In health treatment, imaging and classifying the interference patterns of neural dynamics may support the existing methods of allocating consciousness in non-responsive patients. This is vital for decision making and treatment planning, and related to general anaesthesia (Koch, 2018; Sohn, 2019), since there is an ongoing discussion on whether a patient under general anaesthesia may have some experience that is missed by the current practices for assessing consciousness (Boly et al., 2013). Research on the modification of current neural interferences and experiences by sub-neuronal processes can expand the treatment of lesions of the neural system’s executive functions and pain management (Hameroff, 2021; Hameroff and Penrose, 2014). After aligning the levels of entropy in neural systems (Demertzis et al., 2019; Luppi et al., 2019) with entropy of subjective reality and corresponding levels of consciousness, it can clarify the presence and diversity of subjective experience in the artificial, biological, and computer systems, which is necessary to resolve some of the most recent ethical dilemmas (Reardon, 2020; Yuste and Goering, 2017).

7.3. Creating intelligence and social studies

This review allows one to infer that to create artificial intelligence (Dehaene et al., 2017; Koch, 2018; Segal and Clark, 2019) and model natural consciousness (Abbott, 2020, 2021), focusing on the global connectivity between domain systems (Dehaene et al., 2017), integration of self-recursive elements (Tononi et al., 2016), and other computational methods may be insufficient (Frégacq, 2017). To have a subjective experience, this system must be able to align with the stochasticity of the world (Northoff, 2018; Segal and Clark, 2019) and possess intrinsic time and space (Buzsáki and Llinás, 2017; Northoff and Huang, 2017; Northoff et al., 2020; Yeshurun et al., 2021), which result from the overlap between intrinsic and stimulated dynamics. To obtain human-like consciousness, the functional ability to simultaneously operate with several objects and the need to preserve social cohesion are vital (Hari et al., 2015; Herrmann et al., 2007; Tomasello, 2020).

In modelling social dynamics, this research predicts that each circumstance determines a particular optimal social cohesion level, below which the population cannot resist the impact of more unitarian and numerous groups (Vaesen et al., 2019) and will be subject to cultural regress (Strasberg and Creanza, 2021), and above which the population will lose the advantages of individual adaptability (Shennan and Sear, 2021). Therefore, the moral norms of liberal rights and social inclusiveness are supported by scientific evidence.

7.4. Philosophy and worldview

I believe that suggested conceptualisation of consciousness and subjective reality is in line with the world-brain ontology, consideration of consciousness beyond its content, and that scientific study must accept the vantage point beyond the mind argued by Northoff (2018). Furthermore, already at the middle of the 20th century it was proposed that the matter is not a conglomerate of the things, but rather various forms of energy; thus, the scientific study should focus on revealing principles of the energy transformation (Heisenberg, 1958). Since suggested framework assumes that subjective reality has a real existence, it definitely fits the criteria of being a form of energy. Therefore, this approach is purely materialistic, with the core idea of an unceasing transformation of matter, while any abstract principles and ideas are attempts to find regularities in the environment and deeply grounded in the existed culture (Han, 2017). Since there are no external criteria of truth, like transcendental mind, the scientific studies of consciousness may rely only on the careful investigation of the known facts and testing predictions. Such an approach is critically important for the contemporary world to oppose various forms of religious and political dogmatism, intentional and unintentional biases, and promote the richness of the modes of thought.

Data availability

Raw data and other supplementary material are available at the following repository: osf.io/7zpcj.

Author contributions

Ilya A. Kanaev conducted all the research relevant to this article and wrote the manuscript.

Declaration of Competing Interest

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