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Insights in Consciousness Research 2021

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Insights in consciousness research 2021

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Editorial: Insights in consciousness research 2021

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Editorial on the Research Topic
Insights in consciousness research 2021

In recent years, multiple theories have been proposed and are being tested to advance consciousness science (Seth and Bayne, 2022). Critical reviews focusing on these theories have proposed criteria for evaluating such theories (Doerig et al., 2021) and evaluated their potential convergence (Northoff and Lamme, 2021). The Research Topic on insights in consciousness research focuses on some critical aspects in consciousness research.

The paper by Marchetti focuses on the phenomenal aspects of consciousness (PAC), more specifically the "why" of the PAC, deriving an explanation for the evolutionary and functional understanding of consciousness. For him, PAC allows an agent to have a sense of self and provides information on how various mental operations influence the self. Marchetti uses a notion of information that is available only for an agent or self to understand the PAC, which forms the basis of conscious information processing. He argues that conscious information processing is due to two important components, self, and attention. In a functional perspective, self as a process reduces the complexity of the organism into a "single voice," while attention focuses on specific aspects of the self. He argues that attentional activity on the state of self modulates the "energy level" of the neural substrate underlying the attentional activity. According to this perspective, different dimensions of PAC like quantitative, qualitative, hedonic, temporal, and spatial are associated with different features of modulation of energy level of the organ of attention and sense of self involved.

Amongst the prominent current theories of consciousness is the integrated information theory (IIT: Oizumi et al., 2014), which depends on measures of complexity (Arsiwalla and Verschure, 2018). There have been multiple criticisms of IIT [see Singhal et al. (2022) for a criticism based on temporal phenomenology]. The paper by Koculak and Wierzchoń argues that the focus of those studying the theoretical and empirical basis of IIT has been primarily on the states of consciousness and not directly on the contents of consciousness itself. They argue for the need to pay attention to complexity measures in understanding our conscious experience in terms of both states and contents of our conscious experience, while IIT provides only a quantitative measure of the degree of integration. The authors point to the need to dissociate the use of complexity measures from the ontological assumptions of IIT so that empirical studies on neural correlates of consciousness can study whether complexity measures can directly quantify properties of the contents of consciousness. One example they point out is the fMRI study by Boly et al. (2015) that measures Lempel-Ziv complexity under different stimulus conditions and found a difference in complexity. They argue that more studies investigating complexity measures under different conditions of consciousness (for example, conscious vs. unconscious perception) are needed.

Some have argued that we need to go beyond physicalist theories of consciousness. The paper by Wahbeh et al. briefly discusses physicalist theories including global workspace, higher order thought theories, IIT, and predictive processing/reentrant theories. They point to a lack of consensus regarding these theories, as these theories make different assumptions and explain address different phenomena. Then, the authors propose non-local theories of consciousness as a way to resolve the "hard problem" (Chalmers, 1996). They discuss a set of theories with many of them being of panpsychist nature, but it is also not clear that there is any consensus regarding these theories. Finally, they discuss a set of unexplained non-local phenomena which support non-local theories of consciousness. Authors then propose to consider in future research both local and non-local theories of consciousness and suggest how they could be further integrated.

In terms of states of consciousness, it is important to understand the phenomenological aspects and mechanistic underpinnings of different altered states of consciousness that include dreaming, hypnosis, and meditation. In this direction, the article by Penazzi and De Pisapia compares research and findings on hypnosis and meditation. The phenomenology of hypnosis includes dissociation, absorption, and suggestibility, while for meditation three general categories are described, i.e., focused-attention, open monitoring, and deconstructive meditation, which differ in terms of attention, metacognition, and experience of the self. Both hypnosis and meditation seem to involve relaxation, as they decrease the sympathetic response and increase the parasympathetic tone but differ in terms of volition and control (Dienes et al., 2022), as hypnosis is supported by an external subject with suggestive methodologies, while meditative states are typically self-induced. This leads to potential differences in meta-awareness between these two states with lesser meta-awareness in hypnosis and more meta-awareness in meditators, which can be understood in the context of HOT theory (Dienes et al., 2022). Finally, the authors point out the need for further studies comparing these conscious states, in particular, through EEG studies.

In fact, EEG is an optimal methodology to investigate altered states of consciousness, as it has a good temporal resolution, which allows to study transient and dynamics states of consciousness such as the so-called microstates, i.e., stable global patterns of electrophysiological brain activity that last about 100 ms. EEG recorded during different states of consciousness can be analyzed to identify such microstates. Bréchet and Michel discuss the presence of and changes in microstates during mind wandering, meditation, sleep and anesthesia. For example, they discuss the presence of two microstates during episodic memory retrieval, which is linked to fMRI resting state networks and the dynamics indicate switching between these microstates associated with different aspects of memory retrieval.

Since the operationalization of consciousness as a stream of information (James, 1890), we have since developed theories (Marchetti; Penazzi and De Pisapia; Wahbeh et al.), methods (Koculak and Wierzchoń), and technical skills (Bréchet and Michel) to advance our understanding of our experience as human beings. Overall, the papers included in this Research Topic give a glimpse of the complexity and open-endedness of the current debate in consciousness studies and contributes to consciousness research, which has a tremendous impact on research, clinical, and ethical aspects (Michel et al., 2019).

Author contributions

All authors substantially contributed to this paper and approved it for publication.

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References

Arsiwalla, X. D., and Verschure, P. (2018). Measuring the complexity of consciousness. *Front. Neurosci.* 12, 424. doi: 10.3389/fnins.2018.00424

Boly, M., Sasai, S., Gosseries, O., Oizumi, M., Casali, A., Massimini, M., et al. (2015). Stimulus set meaningfulness and neurophysiological differentiation: A functional magnetic resonance imaging study. *PLoS ONE* 10, e0125337. doi: 10.1371/journal.pone.0125337

Chalmers, D. (1996). The Conscious Mind: In Search of a Fundamental Theory. New York, NY: Oxford University Press.

Dienes, Z., Lush, P., Palfi, B., Roseboom, W., Scott, R., Parris, B., et al. (2022). Phenomenological control as cold control. *Psychol. Consciousness* 9, 101–116. doi: 10.1037/cns0000230

Doerig, A., Schurger, A., and Herzog, M. H. (2021). Hard criteria for empirical theories of consciousness. *Cogn. Neurosci.* 12, 41–62. doi: 10.1080/17588928.2020.1772214

James, W. (1890). *The Principles of Psychology*. New York, NY: Holt. doi: 10.1037/10538-000

Michel, M., Beck, D., Block, N., Blumenfeld, H., Brown, R., Carmel, D., et al. (2019). Opportunities and challenges for a maturing science of consciousness. *Nat. Hum. Behav.* 3, 104–107. doi: 10.1038/s41562-019-0531-8

Northoff, G., and Lamme, V. (2021). Neural signs and mechanisms of consciousness: Is there a potential convergence of theories of consciousness in sight? *Neurosci. Biobehav. Rev.* 118, 568–587. doi: 10.1016/j.neubiorev.2020.07.019

Oizumi, M., Albantakis, L., and Tononi, G. (2014). From the phenomenology to the mechanisms of consciousness: Integrated information theory 3.0. *PLoS Comput. Biol.* 10, e1003588. doi: 10.1371/journal.pcbi.1003588

Seth, A. K., and Bayne, T. (2022). Theories of consciousness. *Nat. Rev. Neurosci.* 23, 439–452. doi: 10.1038/s41583-022-00587-4

Singhal, I., Mudumba, R., and Srinivasan, N. (2022). In search of lost time: Integrated information theory needs constraints from temporal phenomenology. *Philos. Mind Sci.* 3, 13. doi: 10.33735/phimisci.2022.9438

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EEG Microstates in Altered States of Consciousness

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Conscious experiences unify distinct phenomenological experiences that seem to be continuously evolving. Yet, empirical evidence shows that conscious mental activity is discontinuous and can be parsed into a series of states of thoughts that manifest as discrete spatiotemporal patterns of global neuronal activity lasting for fractions of seconds. EEG measures the brain's electrical activity with high temporal resolution on the scale of milliseconds and, therefore, might be used to investigate the fast spatiotemporal structure of conscious mental states. Such analyses revealed that the global scalp electric fields during spontaneous mental activity are parceled into blocks of stable topographies that last around 60–120 ms, the so-called EEG microstates. These brain states may be representing the basic building blocks of consciousness, the "atoms of thought." Altered states of consciousness, such as sleep, anesthesia, meditation, or psychiatric diseases, influence the spatiotemporal dynamics of microstates. In this brief perspective, we suggest that it is possible to examine the underlying characteristics of self-consciousness using this EEG microstates approach. Specifically, we will summarize recent results on EEG microstate alterations in mind-wandering, meditation, sleep and anesthesia, and discuss the functional significance of microstates in altered states of consciousness.

Keywords: altered states of consciousness, EEG microstates, meditation, dreaming, mind-wandering, anesthesia

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INTRODUCTION

Consciousness represents all that we subjectively experience, i.e., the qualitative feeling within an experience, e.g., the warmth of home or cherished memories of loved ones. An essential aspect of consciousness is its link with a self, which is the subject of conscious experience. The brain generates experiences day after day. Understanding the neuronal architecture that forms conscious experiences is one of the fundamental questions of cognitive neuroscience. More than 130 years ago, James (1890) pointed out that *"As we take a general view on the wonderful stream of our consciousness, what strikes us first is this different pace of its parts. Like a bird's life, it seems to be made of an alternation of flights and perchings."* Even though self-consciousness seems to be continuous as a stream of water, it appears to be composed of *"perchings,"* which may represent brain states with specific mental contents, and *"brief flights,"* which may be the fast transitions between mental states. Interestingly, a number of theories propose that consciousness may be parceled into discrete states lasting around 100–200 ms (Efron, 1970; Bressler, 1995; Rabinovich et al., 2001; Deco et al., 2011). Therefore, it seems that dynamics that underlie these subjective experiences have to describe the brain functioning in this short time range.

EEG measures the brain's electrical activity with high temporal resolution (i.e., on the scale of milliseconds) and, therefore, might be used to investigate the temporal dynamics of conscious mental states (Michel and Koenig, 2018). Interestingly, Lehmann (1987) suggested that these short-lasting mental states may be represented by stable global patterns of electrophysiological brain activity, the so-called *"microstates of cognition"* or *"atoms of thoughts."* The time window during which spatially distinct brain processes are accepted as a short EEG microstate lasts between 60 and 120 ms (Koenig et al., 2002; Michel and Koenig, 2018). While the most dominant EEG microstate maps are highly reproducible within and between participants (Koenig et al., 2002; Khanna et al., 2014; Tomescu et al., 2018; da Cruz et al., 2020; Zanesco et al., 2020), their temporal dynamics are sensitive to the momentary state of the brain. Altered states of consciousness (e.g., sleep, disorders of consciousness, anesthesia, hypnosis, or meditation) influence the temporal dynamics of microstates (Katayama et al., 2007; Brodbeck et al., 2012; Panda et al., 2016; Faber et al., 2017; Stefan et al., 2018; Shi et al., 2020; Bréchet et al., 2021). The inner self is unique to each person. We may assume that others have similar inner experiences, but so far, we cannot directly measure the inner self of others. In this perspective, we are going to argue that it is possible to explore the underlying characteristics of self-consciousness and summarize our current findings. Recent experimental studies have focused on establishing a link between subjective conscious experiences and measurable neuronal activity. We will question "How can we capture the self-relevant, conscious thoughts of the wandering mind?" then we will ask 2. "Can meditation alter conscious brain states?" 3. We will assess 3. "What happens with conscious experiences during sleep?" and finally 4. "How does consciousness fade-out during anesthesia?"

THE CONCEPT OF EEG MICROSTATES

One way to globally represent the momentary brain activity resulting from concomitant active brain areas is to record EEG with a whole-scalp array of electrodes and map the potential scalp field at each moment in time (Lehmann, 1987; Michel et al., 2009). By inspecting the temporal evolution of these potential scalp maps of ongoing resting state EEG, Dietrich Lehmann made the seminal observation that the spatial configuration (the topography) of the potential map remains stable for short periods of time and then rapidly switches to a new configuration in which it remains stable again. He called these periods of stability, which lasted around 100 ms, the EEG microstates, where the term "micro" refers to the temporal (the briefness) and not to the spatial scale. In 1990, Lehmann suggested that these brief episodes of topographic stability of the global electric field represent the "atoms of thought" (Lehmann, 1990), without yet strong supporting evidence for this analog.

A commonly used approach to determine the most dominant topographies in spontaneous EEG is cluster analysis (Pascual-Marqui et al., 1995). When applying this data-driven method, a striking observation is that a few prototypical maps dominate the recorded signal, explaining around 70–80% of the variance (Koenig et al., 2002; Custo et al., 2017). While the topography of these maps is very similar across studies (for reviews see Khanna et al., 2015; Michel and Koenig, 2018), the most fundamental observation is that these few maps are not randomly appearing in time, but they remain stable for short periods of around 80–150 ms (Koenig et al., 2002). Thus, the ongoing spontaneous EEG is parceled into short segments represented by one specific topography that repeats in time in variable sequence and duration. Given the above described theories of parcellation of consciousness in discrete states that last around 100–200 ms, it is intriguing to assume that EEG microstates are the electrophysiological manifestation of these conscious states (Bressler and Kelso, 2001; Changeux and Michel, 2004), representing short periods of synchronized activity of large-scale functional networks (Seeber and Michel, 2021).

EEG MICROSTATES IN SELF-RELATED MIND-WANDERING

The temporal structure of spontaneous mentation is key to forming a meaningful stream of consciousness. The human perception appears continuous, dynamic, and unsegmented (Zacks et al., 2001). Neuroscience research embraced the tremendous attention paid to the resting brain's activity and dramatically changed our view on mind-wandering (Smallwood and Schooler, 2015; Christoff et al., 2016). Until now, the precise functional role of resting-state networks, which may represent distinct states of consciousness, remains unclear. Previous studies have tried to relate EEG microstates to ongoing mental activity. For example, Seitzman et al. (2017) altered the temporal features of the 4 canonical microstates by instructing their participants to either mentally subtract numbers or to spontaneously mind-wander. They found a significant decrease in occurrence (i.e., the frequency of occurrence independent of its individual duration) and duration (i.e., the average duration that a given microstate remains stable) of microstate C and an increase in microstate D during mental calculation, supporting the hypothesis that state D is related to the attentional system. In addition, Milz et al. (2016) showed increased coverage (i.e., the fraction of total recording time for which a given microstate is dominant) of microstate A while visualizing and coverage of microstate B while verbalizing. Thus, these studies show that the temporal dynamics of EEG microstates may be sensitive to instruction and changes in the content of spontaneous mentation.

A few studies have examined associations between microstates and spontaneous thought using a retrospective questionnaire administered to participants after a short period of rest. Pipinis et al. (2017) found a negative association between microstate C and experienced somatic awareness (SA) of the subsequent Amsterdam Resting-State Questionnaire (ARSQ). SA was evaluated by questions related to bodily self-consciousness (e.g., "I was conscious of my body"; "I thought about my heartbeat"; "I thought about my breathing." In a follow-up study, Tarailis et al. (2021) showed that microstate F was associated with SA, microstates C, E, and G were related to the comfort domain and microstates B and C related to the self-domain. Zanesco et al. (2021b) directly examined the association between episodes of mind wandering and microstates in a cognitive task with embedding experience sampling probes to capture moments of on-task vs. off-task focus. The authors found that self-reported mind wandering and response time variability differentiated pre-stimulus EEG microstate dynamics during a sustained attention task. Further, Zanesco et al. (2021a) found associations between self-reported aspects of spontaneous thought and temporal parameters of EEG microstates and thus pointed out the relevance of using retrospective questionnaires for understanding intrinsic brain activity.

Our recent study (Bréchet et al., 2019) examined the spatiotemporal dynamics of large-scale brain networks associated with particular thoughts. Participants were instructed to direct their thoughts to their past, self-related memories or mental, self-unrelated calculation to examine the large-scale networks underlying the internal conscious thoughts. We examined the spatiotemporal dynamics of brain activity with high-resolution 7-Tesla fMRI and high-density EEG in two separate sessions. We expected the fMRI data to confirm that the default mode network comprises distinct sub-systems related to visual imagery and autobiographical memory retrieval. We then hypothesized that the EEG microstate analysis would reveal that these functional sub-networks are not continuous but relatively temporally parsed. First, the fMRI data confirmed that sub-networks of the default mode network are activated during episodic memory retrieval, and these subnetworks show distinct connectivity patterns. Second, EEG microstate analysis showed two microstates that increased in duration and occurrence during autobiographic episodic memory retrieval and another microstate during mental arithmetics (**Figure 1-1**).

Interestingly, while the sources of the two microstates that dominated during memory retrieval were very similar to the two fMRI resting state networks, the temporal analysis revealed a continuous switching between the two networks over time in the sub-second range. The microstate analysis thus allowed to disentangle the sub-parts of thoughts related to the conscious experience of episodic autobiographic memory, i.e., visualization of the scene and the self. Using functional connectivity analysis in the source space, we showed in a follow-up study that autobiographical memory retrieval emerges during a precise theta-gamma phase-amplitude coupling between the medial temporal lobe and the prefrontal and the posterior cingulate cortex (Roehri et al., 2022).

Sometimes the conscious mind moves spontaneously from one thought to another. However, at other times, it keeps coming back to the same thought, drawn by a particular past event or an emotional experience. While a healthy person naturally balances between different types of thoughts that make sense to both the individual and the world, someone with a mental health issue may lose control over the natural flow of the wandering mind and continuously cycles through a series of rigid thoughts that are at odds with reality. To capture the stream of ongoing thoughts is challenging yet essential to better comprehend the composition of healthy and pathological thoughts. Several studies have shown that the temporal dynamics of EEG microstates are modulated by pathologies that lead to aberrant mind states such as schizophrenia or depression (Lehmann et al., 2005; Tomescu et al., 2015; Rieger et al., 2016; Damborska et al., 2019; da Cruz et al., 2020; Murphy et al., 2020).

EEG MICROSTATES IN SELF-FOCUSED MEDITATION

Brain activity constantly fluctuates in and out of different mental states that are stable for fractions of seconds. Only one epoch or state of conscious content can be present at a time (Seth and Baars, 2005). If EEG microstates are indicative of the level of consciousness, then they can be modulated by different states of mind. Panda et al. (2016) recorded simultaneous EEG-fMRI while experienced participants meditated. This study showed that at rest, the meditators exhibited increased duration and occurrence of DMN related microstate C, which further increased during meditation. Katayama et al. (2007) showed that a decrease in microstate C characterized light hypnosis, while deep hypnosis was associated with a reduction of microstate D. The study of Faber et al. (2017) tested two phases of transcendental meditation—transcending (i.e., self-awareness becomes primary) and undirected (i.e., the mind becomes engaged in an undirected stream of thoughts) mentation—and compared them using EEG microstates. Compared to the transcending mentation, undirected mentation was marked by significantly higher coverage and occurrence of microstate C. In comparison, transcending meditation was characterized by higher coverage and occurrence of microstate D.

To examine the effects of internally self-focused meditation, we analyzed the resting-state 64-channel EEG of the participants reported in Ziegler et al. (2019). In this follow-up study (Bréchet et al., 2021), we used the EEG microstate approach to capture resting-state network dynamics before and after the meditation training and compared them to changes before and after placebo sessions. Compared to a placebo condition and the pre-meditation resting EEG data, distinct new microstate topographies appeared after 6 weeks of intensive meditation training. In addition, source analysis identified the fronto-insular-parietal network, including the right insula, superior temporal gyrus, parietal lobule, and frontal gyrus bilaterally (**Figure 1-2**). These brain areas are involved in self-related, multisensory conscious experiences. Our results thus indicate that EEG microstates can capture and monitor sustained changes in conscious mentation induced by breath-focused digital meditation practice and open new avenues for developing novel

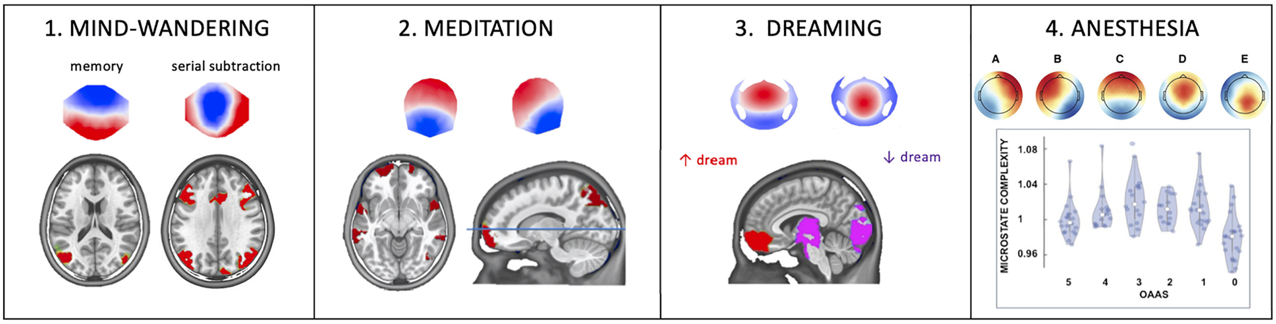

FIGURE 1 | The influence of different functional brain states on EEG microstates. **(1)** Instructing subjects to focus their thoughts on an autobiographical memory increased duration and occurrence of one microstate, while focusing the attention on a serial subtraction task increased duration and occurrence of another microstate. Source localization attributed the memory-specific microstate to the lateral parietal lobe and the arithmetic-specific microstate to the activity of a frontoparietal network (Figure modified with permission from Bréchet et al., 2019). **(2)** Compared to placebo, six weeks of digital meditation training led to a reconfiguration of two of the four predominant microstates whose generators were found in the superior frontal gyrus, the superior temporal gyrus, the insula, the left inferior, and the right superior parietal lobule (Figure modified with permission from Bréchet et al., 2021). **(3)** EEG microstates during dreaming: compared to awake, Non-Rapid Eye Movement Sleep (NREM), dominated by slow-wave activity, selectively increased the Global Explained Variance and duration of two out of five microstates which were localized in the medial and middle frontal gyrus and the posterior cortex and midbrain, respectively. Interestingly, dreaming during NREM sleep further increased the presence of the frontal microstate but decreased the presence of the posterior microstate, indicating a local awakening (less slow-wave) of the posterior cortex (Figure modified with permission from Bréchet et al., 2020). **(4)** EEG microstate during global anesthesia. All five microstates identified in this study were modulated in the same way by different levels of Propofol: they first showed an increase in occurrence and complexity and decrease in duration with moderate sedation, but an inverted behavior with deeper sedation. This u-shaped behavior might be linked to the paradoxical excitation induced by moderate levels of Propofol. OAAS refers to the Observer's Assessment of Alertness/Sedation scale ranging from 5 (awake) to 0 (deep anesthesia) (Figure modified with permission from Artoni et al., 2022).

approaches to treat neuropathological states such as anxiety, hyperactivity, or depression.

EEG MICROSTATES IN SLEEP

Most of us dream every night, although we are unlikely to remember any of our dreams. When we sleep, our brains repeatedly cross a boundary between unconsciousness and dreaming—a particular form of consciousness. Why are we sometimes unconscious, while at other times, we have conscious experiences in the form of dreams? Which brain states determine whether dreams will occur and what prevents us from waking up during these conscious experiences? Clear evidence shows that dreaming can occur in both rapid eye movement (REM) and non-rapid eye movement (NREM) sleep (Stickgold et al., 2001; Nir and Tononi, 2010; Siclari et al., 2018). In a recent study (Bréchet et al., 2020), we showed that two specific microstates dominate during NREM sleep compared to awake, but that these two microstates are differently affected by dreaming during NREM sleep: While microstate D that includes generators in the occipital cortex, the thalamus, and the brainstem becomes activated, i.e., reduced presence of state D during dreaming ("the awakening of the posterior hot zone"), there is an increased deactivation, i.e., increased presence during dreaming of microstate C that encompasses prefrontal brain regions (**Figure 1-3**). The former may account for conscious experiences with rich perceptual content, while the latter may account for why the dreaming brain may undergo executive disconnection and remains asleep. This study thus suggests that NREM sleep consists of alternating brain states whose temporal dynamics determine whether conscious experience in terms of dreams arises.

EEG MICROSTATES UNDER ANESTHESIA

The model put forward in this perspective is that conscious experience relies on the brain's ability to generate a stream of short-lasting global functional states characterized by the synchronized activity of large-scale networks. The EEG microstates are the electrophysiological correlates of these basic building blocks of conscious content. Notably, the temporal dynamics of these momentary states in terms of their frequency of occurrence, duration, and the syntax of transition between them have been demonstrated to be sensitive to changes in the content of conscious experiences (Michel and Koenig, 2018). The temporal dynamics of microstates are based on metastability that allows for a continuous balance between stability and disorder and a rapid and flexible switch from one state to the other (Tognoli and Kelso, 2014). Any change in the typical temporal structure of state transitions, whether prolonged staying in a given state or disordered transitions between states, will likely result in alterations in the global state of consciousness.

To directly test the modifications of the microstate's temporal dynamics by altered states of consciousness, we investigated the spatio-temporal properties of EEG microstates in 23 surgical patients from their awake state to unconsciousness, induced by stepwise increasing concentrations of the intravenous anesthetic propofol (Artoni et al., 2022). Loss of consciousness was characterized by increasing duration and spatial correlation of all microstates (i.e., the mean spatial correlation of the microstate map with the global field power peak maps within the spatially filtered dataset), decreasing occurrence of all microstates, and reduced complexity assessed by the Lempel-Ziv complexity index (i.e., a more heterogeneous succession of microstates) of the microstate sequences. A similar EEG microstate complexity measure has been recently tested for aiding early diagnosis of Alzheimer's disease (Tait et al., 2020). Interestingly, we found a U-shaped effect of propofol from baseline to light sedation and from sedation to surgical anesthesia. Light sedation was characterized by more diverse spatiotemporal EEG microstate patterns with shorter duration, higher density, lower spatial correlation of the microstates, and increased complexity (i.e., reflect simpler and repetitive microstate sequences) of the microstate sequences than awake and deep anesthesia (**Figure 1-4**). This peculiar behavior is probably linked to the paradoxical excitation effect of propofol and other anesthetics at a lower dose, marked by hyperexcitability, disinhibition, loss of effective control, and probably greater awareness of both inside and outside stimuli (Fulton and Mullen, 2000). Such an altered state of consciousness has also been described after using "magic mushroom"—psilocybin, i.e., a naturally occurring psychedelic prodrug, as the "entropic brain" state (Carhart-Harris et al., 2014).

DISCUSSION

The inner self is unique to each person, who is the only one who can access this state. An observer may distinguish various conscious states of others, but the *"self-experience of how it feels"* is restricted to the inner self of the involved person. As James (1890) described, "*when I wake up, I do not have to question 'who am I,' because I still have my own thoughts that seem to be continuous and represent my personal past.*" One may assume that others have similar inner experiences, but nobody else can directly experience the inner self of others. In this brief perspective, we have argued that it is possible to examine the underlying characteristics of self-consciousness using the EEG microstates approach. Specifically, we summarized recent EEG microstate alterations in mind-wandering, meditation, sleep, and anesthesia. We presented results from our recent study that showed that the microstate analysis allows us capture the conscious experience of episodic autobiographic memory. We then used the EEG microstate approach to capture resting-state network dynamics before and after the meditation training and showed distinct new microstate topographies after the intensive meditation training, which opens new possibilities for treating neuropathological states such as depression or anxiety.

In another study, we claim that the NREM sleep consists of alternating brain states whose temporal dynamics determine whether conscious experiences, i.e., dreams, may arise or not. Finally, we examined the temporal dynamics of EEG microstates from awake state to the loss of consciousness, which allowed us to capture an altered state of consciousness.

Consciousness is detectable in the behavior of others, but none of the neuroimaging techniques can thoroughly read the mind of private thoughts (Lee and Kuhl, 2016). While functional neuroimaging studies using fMRI demonstrated that the brain is intrinsically organized in large-scale networks, the relation between these slowly fluctuating networks and the cognitive activities is questioned because neuronal networks dynamically re-organize in the sub-second time-scale. EEG microstates show such sub-second re-organization and are thus better suited to study the dynamics of spontaneous conscious processes, such as what happens during mind-wandering, dreaming, meditation, or under anesthesia. A better understanding of the relation of EEG microstates to the content of conscious processes and their influence by the global mental state of the brain enables us to elucidate the sensitivity and specificity of these EEG signatures. Furthermore, since EEG is directly related to neuronal activity, a more profound analysis of the relation of EEG microstates to power in different frequency bands (Koenig et al., 2001; Férat et al., 2022) and mechanisms of communication between brain regions will give new insights into the neuronal mechanisms underlying the emergence of conscious thoughts and experiences, and will ultimately help to understand better what happens during altered states of consciousness and what goes wrong in the mind of those with a mental illness.

AUTHOR CONTRIBUTIONS

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REFERENCES

Artoni, F, Maillard, J., Britz, J., Seeber, M., Lysakowski, C., Bréchet, L., et al. (2022). EEG microstate dynamics indicate a U-shaped path to propofol-induced loss of consciousness. *bioRxiv* [Preprint]. doi: 10.1101/2021.10.26.465841

Bréchet, L., Brunet, D., Birot, G., Gruetter, R., Michel, C. M., and Jorge, J. (2019). Capturing the spatiotemporal dynamics of self-generated, task-initiated thoughts with EEG and fMRI. *Neuroimage* 194, 82–92.

Bréchet, L., Brunet, D., Perogamvros, L., Tononi, G., and Michel, C. M. (2020). EEG microstates of dreams. *Sci. Rep.* 10:17069. doi: 10.1038/s41598-020-74075-z

Bréchet, L., Ziegler, D. A., Simon, A. J., Brunet, D., Gazzaley, A., and Michel, C. M. (2021). Reconfiguration of electroencephalography microstate networks after breath-focused, digital meditation training. *Brain Connect.* 11, 146–155. doi: 10.1089/brain.2020.0848

Bressler, S. L. (1995). Large-scale cortical networks and cognition. *Brain Res. Brain Res. Rev.* 20, 288–304.

Bressler, S. L., and Kelso, J. A. (2001). Cortical coordination dynamics and cognition. *Trends Cogn. Sci.* 5, 26–36. doi: 10.1016/s1364-6613(00)01564-3

Brodbeck, V., Kuhn, A., von Wegner, F., Morzelewski, A., Tagliazucchi, E., Borisov, S., et al. (2012). EEG microstates of wakefulness and NREM sleep. *Neuroimage* 62, 2129–2139. doi: 10.1016/j.neuroimage.2012.05.060

Carhart-Harris, R. L., Leech, R., Hellyer, P. J., Shanahan, M., Feilding, A., Tagliazucchi, E., et al. (2014). The entropic brain: a theory of conscious states informed by neuroimaging research with psychedelic drugs. *Front. Hum. Neurosci.* 8:20. doi: 10.3389/fnhum.2014.00020

Changeux, J.-P., and Michel, C. M. (2004). "Mechanism of neural integration at the brain-scale level," in *Microcircuits* eds S. Grillner and A. M Graybiel, (Cambridge, MA: MIT Press). doi: 10.21037/atm-20-4865

Christoff, K., Irving, Z., Fox, K., Spreng, N., and Andrews-Hanna, J. (2016). Mind-wandering as spontaneous thought: a dynamic framework. *Nat. Rev. Neurosci.* 17, 718–731.

Custo, A., Van De Ville, D., Wells, W. M., Tomescu, M. I., Brunet, D., and Michel, C. M. (2017). Electroencephalographic resting-state networks: source localization of microstates. *Brain Connect.* 7, 671–682. doi: 10.1089/brain.2016.0476

Efron, R. (1970). The minimum duration of a perception. *Neuropsychologia* 8, 57–63.

da Cruz, J. R., Favrod, O., Roinishvili, M., Chkonia, E., Brand, A., Mohr, C., et al. (2020). EEG microstates are a candidate endophenotype for schizophrenia. *Nat. Commun.* 11:3089.

Damborska, A., Tomescu, M. I., Honzirkova, E., Bartecek, R., Horinkova, J., Fedorova, S., et al. (2019). EEG resting-state large-scale brain network dynamics are related to depressive symptoms. *Front. Psychiatry* 10:548. doi: 10.3389/fpsyt.2019.00548

Deco, G., Jirsa, V. K., and McIntosh, A. R. (2011). Emerging concepts for the dynamical organization of resting-state activity in the brain. *Nat. Rev. Neurosci.* 12, 43–56.

Faber, P. L., Travis, F., Milz, P., and Parim, N. (2017). EEG microstates during different phases of transcendental meditation practice. *Cogn. Process.* 18, 307–314. doi: 10.1007/s10339-017-0812-y

Férat, V., Seeber, M., Michel, C. M. and Ros, T. (2022). Beyond broadband: towards a spectral decomposition of electroencephalography microstates. *Hum. Brain Mapp.* doi: 10.1002/hbm.25834 [Epub ahead of print].

Fulton, S. A., and Mullen, K. D. (2000). Completion of upper endoscopic procedures despite paradoxical reaction to midazolam: a role for flumazenil? *Am. J. Gastroenterol.* 95, 809–811. doi: 10.1111/j.1572-0241.2000.01866.x

James, W. (1890). *The Principles of Psychology. Reprint 1983, Cambridge, MA: Harvard University Press*. New York, NY: Dover Publications.

Katayama, H., Gianotti, L. R., Isotani, T., Faber, P. L., Sasada, K., Kinoshita, T., and Lehmann, D. (2007). Classes of multichannel EEG microstates in light and deep hypnotic conditions. *Brain Topogr.* 20, 7–14. doi: 10.1007/s10548-007-0024-3

Khanna, A., Pascual-Leone, A., and Farzan, F. (2014). Reliability of resting-state microstate features in electroencephalography. *PLoS One* 9:e114163. doi: 10.1371/journal.pone.0114163

Khanna, A., Pascual-Leone, A., Michel, C. M., and Farzan, F. (2015). Microstates in resting-state EEG: current status and future directions. *Neurosci. Biobehav. Rev.* 49, 105–113. doi: 10.1016/j.neubiorev.2014.12.010

Koenig, T, Prichep, L., Lehmann, D., Sosa, P. V., Braeker, E, Kleinlogel, H., et al. (2002). Millisecond by millisecond, year by year: normative EEG microstates and developmental stages. *Neuroimage* 16, 41–48. doi: 10.1006/nimg.2002.1070

Koenig, T., Marti-Lopez, F., and Valdes-Sosa, P. (2001). Topographic time-frequency decomposition of the EEG. *Neuroimage* 14, 383–390. doi: 10.1006/nimg.2001.0825

Lee, H., and Kuhl, B. A. (2016). Reconstructing perceived and retrieved faces from activity patterns in lateral parietal cortex. *J. Neurosci.* 36, 6069–6082.

Lehmann, D. (1990). "Brain electric microstates and cognition: the atoms of thought," in *Machinery of the Mind* ed. E.R. John, (Boston, MA: Birkhäuser).

Lehmann, D. (1987). "Principles of spatial analysis," in *Methods of Analysis of Brain Electrical and Magnetic Signals* eds A. S. Gevins and A. Remont, (Amsterdam: Elsevier), 309–354.

Lehmann, D., Faber, P. L., Galderisi, S., Herrmann, W. M., Kinoshita, T., Koukkou, M., et al. (2005). Microstate duration and syntax in acute, medication-naive, first-episode schizophrenia: a multi-center study. *Psychiatry Res.* 138, 141–156. doi: 10.1016/j.pscychresns.2004.05.007

Michel, C. M., and Koenig, T. (2018). EEG microstates as a tool for studying the temporal dynamics of whole-brain neuronal networks: a review. *Neuroimage* 180, 577–593. doi: 10.1016/j.neuroimage.2017.11.062

Michel, C. M., Koenig, T., Brandeis, D., Gianotti, L. R. R., and Wackermann, J. (eds.). (2009). *Electrical Neuroimaging* (Cambridge, MA: Cambridge University Press).

Milz, P., Faber, P. L., Lehmann, D., Koenig, T., Kochi, K., and Pascual-Marqui, R. D. (2016). The functional significance of EEG microstates–associations with modalities of thinking. *Neuroimage* 125, 643–656.

Murphy, M., Whitton, A. E., Deccy, S., Ironside, M. L., Rutherford, A., Beltzer, M., et al. (2020). Abnormalities in electroencephalographic microstates are state and trait markers of major depressive disorder. *Neuropsychopharmacology* 45, 2030–2037. doi: 10.1038/s41386-020-0749-1

Nir, Y., and Tononi, G. (2010). Dreaming and the brain: from phenomenology to neurophysiology. *Trends Cogn. Sci.* 14, 88–100. doi: 10.1016/j.tics.2009.12.001

Panda, R., Bharath, R. D., Upadhyay, N., Mangalore, S., Chennu, S., and Rao, S. L. (2016). Temporal dynamics of the default mode network characterize meditation-induced alterations in consciousness. *Front. Hum. Neurosci.* 10:372. doi: 10.3389/fnhum.2016.00372

Pascual-Marqui, R. D, Michel, C. M., and Lehmann, D. (1995). Segmentation of brain electrical activity into microstates: model estimation and validation. *IEEE Trans. Biomed. Eng.* 42, 658–665. doi: 10.1109/10.391164

Pipinis, E., Melynyte, S., Koenig, T., Jarutyte, L., Linkenkaer-Hansen, K., Ruksenas, O., et al. (2017). Association between resting-state microstates and ratings on the amsterdam resting-state questionnaire. *Brain Topogr.* 30, 245–248. doi: 10.1007/s10548-016-0522-2

Rabinovich, M., Volkovskii, A., Lecanda, P., Huerta, R., Abarbanel, H. D., and Laurent, G. (2001). Dynamical encoding by networks of competing neuron groups: winnerless competition. *Phys. Rev. Lett.* 87:068102.

Rieger, K., Diaz Hernandez, L., Baenninger, A., and Koenig, T. (2016). 15 years of microstate research in schizophrenia - where are we? A meta-analysis. *Front. Psychiatry* 7:22. doi: 10.3389/fpsyt.2016.00022

Roehri, N., Brechet, L., Seeber, M., Pascual-Leone, A., and Michel, C. M. (2022). Phase-amplitude coupling and phase synchronization between medial temporal, frontal and posterior brain regions support episodic autobiographical memory recall. *Brain Topogr.* 35, 191–206 doi: 10.1007/s10548-022-00890-4

Seeber, M., and Michel, C. M. (2021). Synchronous brain dynamics establish brief states of communality in distant neuronal populations. *eNeuro* 8, 1–10 doi: 10.1523/ENEURO.0005-21.2021

Seitzman, B. A., Abell, M., Bartley, S. C., Erickson, M. A., Bolbecker, A. R., and Hetrick, W. P. (2017). Cognitive manipulation of brain electric microstates. *Neuroimage* 146, 533–543.

Seth, A. K., and Baars, B. J. (2005). Neural Darwinism and consciousness. *Conscious. Cogn.* 14, 140–168.

Shi, W., Li, Y., Liu, Z., Li, J., Wang, Q., Yan, X., et al. (2020). Non-canonical microstate becomes salient in high density eeg during propofol-induced altered states of consciousness. *Int. J. Neural Syst.* 30:2050005. doi: 10.1142/S0129065720500057

Siclari, F., Bernardi, G., Cataldi, J., and Tononi, G. (2018). Dreaming in NREM sleep: a high-density EEG study of slow waves and spindles. *J. Neurosci.* 38, 9175–9185. doi: 10.1523/JNEUROSCI.0855-18.2018

Smallwood, J., and Schooler, J. W. (2015). The science of mind wandering: empirically navigating the stream of consciousness. *Annu. Rev. Psychol.* 66, 487–518.

Stefan, S., Schorr, B., Lopez-Rolon, A., Kolassa, I. T., Shock, J. P., Rosenfelder, M., et al. (2018). Consciousness indexing and outcome prediction with resting-state eeg in severe disorders of consciousness. *Brain Topogr.* 31, 848–862. doi: 10.1007/s10548-018-0643-x

Stickgold, R., Malia, A., Fosse, R., Propper, R., and Hobson, J. A. (2001). Brain-mind states: I. Longitudinal field study of sleep/wake factors influencing mentation report length. *Sleep* 24, 171–179. doi: 10.1093/sleep/24.2.171

Tait, L., Tamagnini, F., Stothart, G., Barvas, E., Monaldini, C., Frusciante, R., et al. (2020). EEG microstate complexity for aiding early diagnosis of Alzheimer's disease. *Sci. Rep.* 10:17627. doi: 10.1038/s41598-020-74790-7

Tarailis, P., Simkute, D., Koenig, T., and Griskova-Bulanova, I. (2021). Relationship between spatiotemporal dynamics of the brain at rest and self-reported spontaneous thoughts: an EEG microstate approach. *J. Pers. Med.* 11:1216 doi: 10.3390/jpm11111216

Tognoli, E., and Kelso, J. A. (2014). The metastable brain. *Neuron* 81, 35–48. doi: 10.1016/j.neuron.2013.12.022

Tomescu, M. I., Rihs, T. A., Rochas, V., Hardmeier, M., Britz, J., Allali, G., et al. (2018). From swing to cane: sex differences of EEG resting-state temporal patterns during maturation and aging. *Dev. Cogn. Neurosci.* 31, 58–66. doi: 10.1016/j.dcn.2018.04.011

Tomescu, M. I., Rihs, T. A., Roinishvili, M., Karahanoglu, F. I., Schneider, M., Menghetti, S., et al. (2015). Schizophrenia patients and 22q11.2 deletion syndrome adolescents at risk express the same deviant patterns of resting state EEG microstates: a candidate endophenotype of schizophrenia. *Schizophr. Res. Cogn.* 2, 159–165. doi: 10.1016/j.scog.2015.04.005

Zacks, J. M., Braver, T. S., Sheridan, M. A., Donaldson, D. I., Snyder, A. Z., Ollinger, J. M., et al. (2001). Human brain activity time-locked to perceptual event boundaries. *Nat. Neurosci.* 4, 651–655. doi: 10.1038/88486

Zanesco, A. P., Denkova, E., and Jha, A. P. (2021a). Associations between self-reported spontaneous thought and temporal sequences of EEG microstates. *Brain Cogn.* 150:105696. doi: 10.1016/j.bandc.2021.105696

Zanesco, A. P., Denkova, E., and Jha, A. P. (2021b). Self-reported mind wandering and response time variability differentiate prestimulus electroencephalogram microstate dynamics during a sustained attention task. *J. Cogn. Neurosci.* 33, 28–45. doi: 10.1162/jocn_a_01636

Zanesco, A. P., King, B. G., Skwara, A. C., and Saron, C. D. (2020). Within and between-person correlates of the temporal dynamics of resting EEG microstates. *Neuroimage* 211:116631. doi: 10.1016/j.neuroimage.2020.116631

Ziegler, D. A., Simon, A. J., Gallen, C. L., Skinner, S., Janowich, J. R., Volponi, J. J., et al. (2019). Closed-loop digital meditation improves sustained attention in young adults. *Nat. Hum. Behav.* 3, 746–757. doi: 10.1038/s41562-019-0611-9

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Direct comparisons between hypnosis and meditation: A mini-review

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Hypnosis and meditation share phenomenological and neurophysiological features, and their comparison is a topic of growing interest in the scientific literature. In this article, we review a classification of these two kinds of non-ordinary states of consciousness, and discuss the studies that directly compare them. Some findings seem to suggest that hypnosis and meditation are distinct phenomena, while others underline their similarities, but experiments that directly contrast them are still scarce and no consensus has been reached yet. While this comparison could give us fundamental insights into central issues concerning the role of attention, metacognition and executive control in the study of consciousness, it is clear that we are still at the early stages of this research.

KEYWORDS

mindfulness, attention, absorption, contemplation, metacognition, cognitive control, consciousness

Introduction

Hypnotic and meditative states are characterized by a series of changes in subjective experiences from the normal waking state, but the literature is still unclear on similarities and differences (Raz and Lifshitz, 2016).

Common characteristics are a state of general wellbeing and relaxation, accompanied by deep concentration, and mental absorption (Lynn et al., 2012). The induction of both states is used for clinical purposes, particularly when dealing with psychological problems such as depression, anxiety and mental stress, or to relieve chronic pain (Zeidan and Grant, 2016).

On the other hand, the procedures for reaching these states have profoundly different historical bases, and in many cases the reported phenomenology presents substantial differences, thus raising a large number of questions about their mutual positioning (Markovic and Thompson, 2016). A key issue that appears central is the understanding of the role played in both states by metacognition, i.e., the ability to represent, monitor, and control ongoing cognitive processes (Lush et al., 2016). While several meditative and specific hypnotic practices seem to train conscious metacognitive skills (Drigas et al., 2022), several hypnotic techniques seem to act more on basic cognition at an unconscious level, inducing a decline in metacognitive abilities (Dienes et al., 2016).

Given these premises, highlighting similarities and differences between these two states seems to be a precondition in the scientific understanding of human consciousness, to disentangle conscious from unconscious processing, as well as to elucidate the role of metacognition. While important theoretical comparisons are present in the literature (e.g., Raz and Lifshitz, 2016), direct experimental comparisons between hypnosis and meditation are an exception. In this article, we briefly start with a definition of hypnotic and meditative states, then discuss the main comparative theories, and then list the few studies that have attempted direct experimental comparisons.

Phenomenology of hypnosis and meditation

In this section, we describe the main phenomenological aspects that separately characterize hypnosis and meditation.

Phenomenology of hypnosis

Hypnosis is defined as a state of consciousness consisting of focused attention, reduced peripheral awareness, and increased responsiveness to suggestion (Elkins et al., 2015). A typical hetero-induced hypnotic session begins with the hypnotist inducing a state of relaxation in the subject, up to a state of true hypnotic trance. In this state, experience and behavior of the hypnotized subject are modeled in accordance with the hypnotic suggestions. Finally, the session ends with a de-induction procedure (for example a countdown) uttered by the hypnotist (Egner and Raz, 2007).

Hypnotic suggestions can induce a wide range of effects, implemented in therapeutic and experimental contexts, ranging from analgesia and other forms of sensory hallucinations to significant modulations of attentional and executive control processes (Terhune et al., 2002; Drigas et al., 2021). There are three main phenomenological components of the hypnotic state: dissociation, absorption and suggestibility (Cardeña and Spiegel, 1991).

Dissociation is the splitting of mental processes from the main body of consciousness, with simultaneous alterations in the sense of self in acting and volition. Subjects deeply immersed in a hypnotic state, when asked to perform a task in response to hypnotic suggestions, perceive a state of alteration in the sense of voluntariness, as if the tasks were performed outside of their own intentionality (Sadler and Woody, 2010).

Absorption, on the other hand, consists of a focused attention that fully engages the mental resources of individuals (Tellegen and Atkinson, 1974). Attention control processes are central to absorption in hypnosis, and therefore a crucial role is hypothesized for executive functions and the frontal lobes (Parris, 2017).

Finally, suggestibility is the ability to model behavior and subjective experience in accordance with hypnotic suggestions. Suggestibility as a trait in the hypnotic context is referred to as hypnotizability, and therefore as the individual's generic ability to experience what is suggested during hypnosis. For this purpose, specific scales have been constructed that allow the comparison between subjects with differences in the hypnotizability trait (Acunzo and Terhune, 2021).

Phenomenology of meditation

The term meditation refers to a wide variety of contemplative practices, ranging from focused meditation to breath control, visualization or mantra recitations (Matko et al., 2021). These practices engage meditators in repetitive, specific mental trainings aimed at cultivating desired psychological qualities and peculiar states of consciousness. We can divide these practices into three general categories, even though in some protocols they can be used together.

In the first category, specific meditative practices regulate and exercise the meditator's attention toward a specific target (e.g., bodily sensations related to breathing) (Lutz et al., 2008). This concentration is characterized by a perceived state of absorption, with a phenomenological total involvement in a specific experience (e.g., breathing) or task (e.g., visualizing mental images), as opposed to the experience of being continually distracted by extraneous thoughts or stimuli (Pekala, 1991). One special form of focused meditation is mantra recitation, with the repetition of a sound, word or phrase to calm and focus the mind, as in Transcendental Meditation (TM) (Álvarez-Pérez et al., 2022).

The second category includes mindfulness meditation and open monitoring practices, where the attention is opened to present thoughts, sensations, images that come to mind, with the purpose of observing them in a detached and non-judgmental way in the present moment (Raffone and Srinivasan, 2010). Here there is a form of absorption as well, but the mind is not focused on a specific target, instead it operates widely, and the practice is oriented toward the cultivation of meta-awareness (an aspect of metacognition), i.e., the awareness of everything that happens in our experience (Smallwood and Schooler, 2015; Mooneyham and Schooler, 2016).

A third category of meditation practices acts not on the level of individual constructs as in the previous groups, but on the whole self of the practitioner. In this family of practices, sometimes referred to as deconstructive (Dahl et al., 2015), the main activity is to introspectively explore the nature and dynamics of self-related mental processes. This practice unveils a transient or illusory nature of self-representations, which can lead to a progressive deconstruction of the ego's sense and to egolessness (Epstein, 1988).

Theoretical and methodological comparisons between hypnosis and meditation

In this section, we describe the similar and dissimilar phenomenological aspects of the hypnotic and meditative states.

Similarities between hypnosis and meditation

A first overlap between hypnosis and meditation concerns bodily relaxation. Both conditions are states of consciousness achieved by induction procedures that improve relaxation, with corresponding physiological effects. Both hypnosis and meditation show a reduction in sympathetic responses and an increase in parasympathetic tone, although these generalized results are not supported by all the field studies (Tung and Hsieh, 2019; Fernandez et al., 2021).

Secondly, in both states relaxation enhances the development of an effortlessly absorbed state of attention in the present moment. However, it is not yet clear whether the states of hypnotic and meditative absorptions are identical phenomena. In meditative practice, avoiding distractions requires training and effort in novices; in a hypnotic session, individuals are instead absorbed in the suggestions apparently without effort. Some authors underline the psychometric ambiguity of the absorption construct evaluated by the self-assessment questionnaires, suggesting the need to identify a finer level for the definition of different types of absorption (Terhune and Jamieson, 2021).

Lastly, functional magnetic resonance imaging (fMRI) studies that have examined meditation or hypnosis separately show that these states are associated with similar and partially overlapping activation changes in frontal, salience, and default-mode networks, known to be involved in attentional and executive functions (McGeown, 2016). However, these similarities are very difficult to generalize due to the different forms of techniques and tasks included in these two families of practices.

Differences between hypnosis and meditation

A first important difference concerns the methodology: in hypnosis, it is central the hypnotherapist's ability to induce the hypnotic state, whereas in meditation the emphasis is on the autonomous mental practice of the meditator, although both states can be led by real people or audio guides (Häuser et al., 2016; McClintock et al., 2019).

Another difference is that hypnosis depends mainly on the hypnotic suggestibility of the subjects (Oakley and Halligan, 2013), whereas meditative traits can be developed with practice (Kiken et al., 2015). This difference affects experimental designs: while the effects of meditation can be assessed by comparing experienced and novice meditators, the effects of hypnosis are usually assessed by distinguishing between high and low hypnotizable individuals.

An important theoretical framework that highlights the differences between the cognitive mechanisms underlying these two states is the theory of Higher Order Thoughts (HOT; Rosenthal, 2005). In this theory, a mental state can be defined as conscious when a person is aware of living that mental state. In this sense, Dienes et al. (2020) proposed a differentiation between HOT cognitive control and COLD control, that is cognitive control in the absence of accurate metacognitive processes. This form of COLD control during hypnosis can be seen in the alteration of the sense of agency, defined as the experience of being the initiator of an intentional action. From this perspective, COLD hypnotic control is interpretable as a lack of awareness of intentions.

On the other end, in another set of studies in clinical settings and with inductions involving attention and imagery (Drigas et al., 2022), hypnosis appears to have an impact on metacognitive skills and wellbeing, thus opening up to the counterintuitive possibility that unconscious processes can act on metacognitive development.

Related to this, a crucial point of differentiation between hypnosis and meditation concerns the experience of dissociation, as the hypnosis literature agrees that a sense of involuntary action and dissociated volition is experienced during these states (Sadler and Woody, 2010). This appears to be very different from meditative states, where the emphasis is instead on increasing and integrating the meditator's sense of presence into one's experiences. Therefore, some researchers consider hypnosis a form of strategically self-induced deception, while meditation as a form of self-induced intuition (Dienes et al., 2016).

A final point of differentiation concerns the effect of these two states on the experience of being a self. While in hypnosis people report having some sort of hidden observer who was witnessing the suggested execution (e.g., motor response) from a third person perspective, in most meditative states practitioners are initially involved in an effort to observe the flow of their thoughts without being involved in it. As the practice progresses, meditators report a weakening of the first person perspective, to the point, in advanced meditative states, of a sense of dissolution of the boundaries of the self (Epstein, 1988).

Direct experimental contrasts between hypnosis and meditation

Here, we review the studies that directly contrast hypnosis and meditation in experimental settings, arranging them into four different groups.

Contrasting hypnosis and transcendental meditation

The first group includes four studies that compared hypnosis (self or hetero-induced) and TM. Walrath and Hamilton (1975) found no differences in heart rate, respiratory rate reduction, and skin resistance between two groups of experienced meditators who either performed a TM session or performed a self-hypnosis session.

Similar lack of physiological differences were found in Morse et al. (1977), in which participants were monitored during alertness, TM, hypnosis (with only relaxation or with analgesia) and relaxation while awake. Psychophysiological measurements included respiratory rate, heart rate, blood pressure, skin resistance, electroencephalography (EEG), and muscle activity. The results showed differences only with respect to alertness, while there were no significant differences between the states of relaxation, with the exception of muscle activity, which was deeper in meditation. Experientially, participants reported relaxation in hypnosis and meditation as being equally more effective than pure relaxation.

In a third study, Barmark and Gaunitz (1979) compared the effects of TM and audio-recorded hypnosis. As in the two previous studies, physiological data showed no significant differences between hypnosis and TM, particularly in heart rate and skin temperature. A slower respiratory rate was detected during TM. Participants reported that during hypnosis compared to alertness there was greater vividness in mental images and a heightened sense of concentration, along with less attention to environmental stimuli and respiratory sensations. Instead, during TM meditators reported that their bodies became lighter and warmer, and as if time went by faster. Benson et al. (1978) found that high hypnotizable subjects lowered anxiety and systolic blood pressure both in TM and self-hypnosis compared to lows.

Contrasting hypnosis with attention meditation and open monitoring

A second group of studies compared hypnosis with attention and open monitoring meditation. In Nuys (1973), participants performed focused meditation exercises, attention assignments, and hypnotic susceptibility assessments. The results indicated that good concentration is a necessary condition for hypnotic susceptibility, but not sufficient, as some participants who did show good concentration were not suggestible. Spanos et al. (1978, 1980) replicated these results, reporting that hypnotizability is related to a low intrusion rate of distracting thoughts, and therefore to the absorption and vividness of mental images. Heide et al. (1980) showed that highly hypnotizable individuals presented most substantial decrements in anxiety after a 1-week meditation treatment compared to lows, while a brief training in meditation did not modify hypnotic responsivity.

Brown et al. (1983) conducted a study to investigate the phenomenological differences during self-hypnosis, daydreaming, and mindfulness meditation performed during retreats. While self-hypnosis involved more self-referential thinking, memory changes and intense emotions, daydreaming emphasized the presence of spontaneous mental images. Meditation initially involved a difficulty in managing distractions during practice, but with experience, a greater awareness of bodily processes was learned, facing changes in the perception of time and sense of self, with mental processes appearing to slow down and with a vivid awareness, which took on an impersonal quality.

More recently, Semmens-Wheeler and Dienes (2012) in the theoretical framework of HOT theory, underlined a methodological issue: the measurement of the subjective perception of intrusive thoughts is a self-monitoring (meta-awareness) activity, and it is therefore possible that highly hypnotizable individuals are simply not aware of the distracting intrusive thoughts. In this sense, the authors proposed the term “cold absorption” in the context of hypnosis, as opposed to “hot absorption” in experienced meditators. The authors compared the hypnotizability scores of experienced meditators against a database of 500 subjects, finding that the meditators were less suggestible than the average of all other subjects. They therefore hypothesized that meditation and hypnosis are opposite with regard to the role of meta-awareness. This hypothesis was verified in a survey by Lush et al. (2016), in which they investigated the subjective times of awareness of an intention to move, a judgment considered to be of a metacognitive type. They found that more easily hypnotized people are less capable of metacognitive judgment, and therefore attribute the initiation of the intention to move later than experienced meditators, whereas the practice of meditation leads to accurate judgments. Furthermore, a cross-sectional study (Grover et al., 2018) showed that hypnotizability and mindfulness facets where negatively correlated.

Contrasting hypnosis and meditation in the perception of pain

A third group of studies compared hypnosis and meditation in the context of pain sensation, mostly for clinical treatments. In a recent review, De Benedittis (2021) underlines how both hypnosis and meditation attenuate pain, but with both similarities and differences in the multiple neurocognitive mechanisms involved. Both phenomena involve the frontal modulation of pain-related areas, but their role in hypnosis seems to depend on the type of suggestion given, while in meditation depends on the level of practice.

Swain and Trevena (2014) compared the effects of brief mindfulness and hypnosis sessions on resistance to pain caused by a hand placed in cold water at 0 C (Cold Pressor Task, CPT). Both interventions showed their efficacy compared to control in two different modalities: no difference was found on between DVD presentations and in person procedures. Participants, however, reported lower subjective pain scores after hypnosis compared to mindfulness.

Recently, Grover et al. (2021) replicated the previous study, finding no differences in CPT outcomes after a single recorded session of hypnosis or mindfulness meditation. Both conditions, however, modulated changes in self-reported pain perception, but while hypnosis induced a reduction in pain intensity and unpleasant elements of pain, mindfulness only correlated with a reduction in pain intensity.

Williams et al. (2022) evaluated the effectiveness of mindfulness meditation and hypnosis vs. an active control condition (educational training) in a randomized study of U.S. military veterans suffering from chronic pain and depression. The results showed no significant differences immediately after the treatments: however, in the follow-up evaluations at 3 and 6 months, the groups that practiced hypnosis and meditation showed a decrease in the intensity of pain and depression.

Contrasting hypnosis and meditation in electroencephalographic studies

A fourth group of studies concerns hypnosis and meditation comparisons mainly with the use of EEG. Halsband et al. (2009) measured EEG activity during hypnosis and meditation of a single highly hypnotizable subject expert in Vajrayana practice, a form of Tibetan meditation that aims to achieve a state of enhanced cognition and emotions (Amihai and Kozhevnikov, 2014). They report significant differences between the two states in the alpha 1 and theta 2 frequency bands. High amplitudes in the alpha frequency bands were greater under hypnosis in the central and temporal positions, while the alpha frequency in meditation was more pronounced in the frontal positions than in the control. Greater activity in the theta band two was observed only under hypnosis in both hemispheres. While the authors admit that it is difficult to draw conclusions from a study with a single subject and with these variances, it is interesting to report that the two states do not show identical brain activations.

Another one-participant study compared the EEG correlates of one form of TM (Sidhi) with those caused by audio-recorded hypnosis in a man with moderate hypnotic responsiveness (Pekala and Creegan, 2020). The participant showed significant phenomenological differences between the two states, assessed by the Phenomenology of Consciousness Inventory, combined with electrophysiological correlates. A greater alpha and beta activity was found during TM than in hypnosis, with a greater beta in the left prefrontal cortex, and increased global delta activity during hypnosis.

Recently, intracranial EEG was used in three patients with no meditative or hypnotic experience (Bauer et al., 2022). The day after the surgery, patients listened to three different audios guiding to mind-wandering, mindfulness meditation, and an imaginative hypnotic state. The pre-recorded hypnotic procedure consisted of bringing attention to bodily sensations and then imagining visiting a pleasant place. The authors found non-specific and diffuse amplitude modulations in the three conditions. Connectivity analysis revealed common patterns in the three conditions, predominant in the low frequencies (delta, theta, and alpha). The connectivity patterns that were unique to the three conditions predominated in the gamma band, and one-third of the correlations in these models were negative.

Conclusions and future directions

In summary, several theoretical models and some experiments identify points of overlap and points of difference between the hypnotic state and the meditative state. In particular, hypnosis appears to be a form of attention focalization supported by an external expert in suggestion methodologies, with prominent imaginative elements and with a dissociation of executive control. Meditative states induce a state of absorption and concentration, but these are typically self-induced, and are forced through numerous practice sessions, which over time can lead to a progressive integration into executive control and—in the long run—to a decrease in the differentiation between the self and the external world.

The large number of meditative practices and the many possible hypnotic inductions open to a combinatorial explosion of interesting experimental contrasts, many of which have not been yet performed. The experiments that directly investigated these similarities and differences are currently only preliminary, although they begin to show phenomenological differences involving metacognition, absorption and executive control, while psychophysiological and EEG studies are too few to draw any kind of meaningful conclusion.

To better understand these states of consciousness and their relationships with ordinary states, it is necessary to increase research efforts, both from the point of view of theoretical models and the collection of data that make a direct comparison between hypnosis and meditation.

Author contributions

GP and ND contributed equally to the literature search, literature analysis, and writing of the manuscript.

Both authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Acunzo, D. J., and Terhune, D. B. (2021). A critical review of standardized measures of hypnotic suggestibility. *Int. J. Clin. Exp. Hypn.* 69, 50–71. doi: 10.1080/00207144.2021.1833209

Álvarez-Pérez, Y., Rivero-Santana, A., Perestelo-Pérez, L., Duarte-Díaz, A., Ramos-García, V., Toledo-Chávarri, A., et al. (2022). Effectiveness of mantra-based meditation on mental health: a systematic review and meta-analysis. *Int. J. Environ. Res. Public Health* 19, 3380. doi: 10.3390/ijerph19063380

Amihai, I., and Kozhevnikov, M. (2014). Arousal vs. relaxation: a comparison of the neurophysiological and cognitive correlates of Vajrayana and Theravada meditative practices. *PLoS ONE* 9, e102990. doi: 10.1371/journal.pone.0102990

Barmark, S. M., and Gaunitz, S. C. (1979). Transcendental meditation and heterohypnosis as altered states of consciousness. *Int. J. Clin. Exp. Hypn.* 27, 227–239. doi: 10.1080/00207147908407564

Bauer, P. R., Sabourdy, C., Chatard, B., Rheims, S., Lachaux, J.-P., Vidal, J. R., et al. (2022). Neural dynamics of mindfulness meditation and hypnosis explored with intracranial EEG: a feasibility study. *Neurosci. Lett.* 766, 136345. doi: 10.1016/j.neulet.2021.136345

Benson, H., Frankel, F. H., Apfel, R., Daniels, M. D., Schniewind, H. E., Nemiah, J. C., et al. (1978). Treatment of anxiety: a comparison of the usefulness of self-hypnosis and a meditational relaxation technique. *Psychother. Psychosom.* 30, 229–242. doi: 10.1159/000287304

Brown, D., Forte, M., Rich, P., and Epstein, G. (1983). Phenomenological differences among self hypnosis, mindfulness meditation, and imaging. *Imagin. Cogn. Pers.* 2, 291–309. doi: 10.2190/JWC1-AXLY-6R0L-G2NK

Cardeña, E., and Spiegel, D. (1991). *Suggestibility, Absorption, and Dissociation: An Integrative Model of Hypnosis*, ed J. F. Schumaker (New York: Taylor & Frances/Routledge), 93–107.

Dahl, C. J., Lutz, A., and Davidson, R. J. (2015). Reconstructing and deconstructing the self: cognitive mechanisms in meditation practice. *Trends Cogn. Sci.* 19, 515–523. doi: 10.1016/j.tics.2015.07.001

De Benedittis, G. (2021). Neural mechanisms of hypnosis and meditation-induced analgesia: a narrative review. *Int. J. Clin. Exp. Hypn.* 69, 363–382. doi: 10.1080/00207144.2021.1917294

Dienes, Z., Lush, P., Palfi, B., Roseboom, W., Scott, R., Parris, B., et al. (2020). *Phenomenological Control as Cold Control. Psychology of Consciousness: Theory, Research, and Practice*. Washington, DC: American Psychological Association.

Dienes, Z., Lush, P., Semmens-Wheeler, R., Parkinson, J., Scott, R., and Naish, P. (2016). "Hypnosis as self-deception; meditation as self-insight," in *Hypnosis and Meditation: Toward an Integrative Science of Conscious Planes*, eds A. Raz, and M. Lifshitz (Oxford, UK: Oxford University Press), 107–128.

Drigas, A., Mitsea, E., and Skianis, C. (2021). The role of clinical hypnosis and VR in special education. *Int. J. Recent Contribut. Eng. Sci. IT* 9, 4–17. doi: 10.3991/ijes.v9i4.26147

Drigas, A., Mitsea, E., and Skianis, C. (2022). Clinical hypnosis & VR, subconscious restructuring- brain rewiring & the entanglement with the 8 pillars of metacognition X 8 layers of consciousness X 8 intelligences. *Int. J. Online Eng.* 18, 78–95. doi: 10.3991/ijoe.v18i01.26859

Egner, T., and Raz, A. (2007). "Cognitive control processes and hypnosis," in *Hypnosis and Conscious States: The Cognitive Neuroscience Perspective*, ed G. A. Jamieson (Oxford, UK: Oxford University Press), 29–50. doi: 10.1080/00029157.2007.10401595

Elkins, G. R., Barabasz, A. F., Council, J. R., and Spiegel, D. (2015). Advancing research and practice: the revised APA Division 30 definition of hypnosis. *Am. J. Clin. Hypn.* 57, 378–385. doi: 10.1080/00029157.2015.1011465

Epstein, M. (1988). The deconstruction of the self: ego and "egolessness" in Buddhist insight meditation. *J. Transpers. Psychol.* 20, 61–69.

Fernandez, A., Urwicz, L., Vuilleumier, P., and Berna, C. (2021). Impact of hypnosis on psychophysiological measures: a scoping literature review. *Am. J. Clin. Hypn.* 64, 36–52. doi: 10.1080/00029157.2021.1873099

Grover, M. P., Jensen, M. P., Patterson, D. R., Gertz, K. J., and Day, M. A. (2018). The association between mindfulness and hypnotizability: clinical and theoretical implications. *Am. J. Clin. Hypn.* 61, 4–17. doi: 10.1080/00029157.2017.1419458

Grover, M. P., Jensen, M. P., Ward, L. C., Ehde, D. M., Mattingley, J. B., Thorn, B. E., et al. (2021). An experimental investigation of the effects and mechanisms of mindfulness meditation versus self-hypnosis versus an attention control on cold pressor outcomes. *Mindfulness* 12, 923–935. doi: 10.1007/s12671-020-01556-7

Halsband, U., Mueller, S., Hinterberger, T., and Strickner, S. (2009). Plasticity changes in the brain in hypnosis and meditation. *Contemp. Hypn.* 26, 194–215. doi: 10.1002/ch.386

Häuser, W., Hagl, M., Schmierer, A., and Hansen, E. (2016). The efficacy, safety and applications of medical hypnosis: a systematic review of meta-analyses. *Deutsch. Ärztebl. Int.* 113, 289–296. doi: 10.3238/arztebl.2016.0289

Heide, F. J., Wadlington, W. L., and Lundy, R. M. (1980). Hypnotic responsivity as a predictor of outcome in meditation. *Int. J. Clin. Exp. Hypn.* 28, 358–366. doi: 10.1080/00207148008409864

Kiken, L. G., Garland, E. L., Bluth, K., Palsson, O. S., and Gaylord, S. A. (2015). From a state to a trait: trajectories of state mindfulness in meditation during intervention predict changes in trait mindfulness. *Pers. Indiv. Diff.* 81, 41–46. doi: 10.1016/j.paid.2014.12.044

Lush, P., Naish, P., and Dienes, Z. (2016). Metacognition of intentions in mindfulness and hypnosis. *Neurosci. Consci.* 2016, niw007. doi: 10.1093/nc/niw007

Lutz, A., Slagter, H. A., Dunne, J. D., and Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends Cogn. Sci.* 12, 163–169. doi: 10.1016/j.tics.2008.01.005

Lynn, S., Malaktaris, A., Maxwell, R., Mellinger, D. I., and van der Kloet, D. (2012). Do hypnosis and mindfulness practices inhabit a common domain? Implications for research, clinical practice, and forensic science. *J. Mind Body Regul.* 2, 12–26.

Markovic, J., and Thompson, E. (2016). *Hypnosis and Meditation: A Neurophenomenological Comparison*. Oxford, UK: Oxford University Press. doi: 10.31231/osf.io/eh237

Matko, K., Ott, U., and Sedlmeier, P. (2021). What do meditators do when they meditate? Proposing a novel basis for future meditation research. *Mindfulness* 12, 1791–1811. doi: 10.1007/s12671-021-01641-5

McClintock, A. S., McCarrick, S. M., Garland, E. L., Zeidan, F., and Zgierska, A. E. (2019). Brief mindfulness-based interventions for acute and chronic pain: a systematic review. *J. Alternat. Complement. Med.* 25, 265–278. doi: 10.1089/acm.2018.0351

McGeown, W. J. (2016). *Hypnosis, Hypnotic Suggestibility, and Meditation: An Integrative Review of the Associated Brain Regions and Networks*. Oxford, UK: Oxford University Press.

Mooneyham, B. W., and Schooler, J. W. (2016). "Mind wandering and meta-awareness in hypnosis and meditation," in *Hypnosis and Meditation: Towards an Integrative Science of Conscious Planes*, eds A. Raz, and M. Lifshitz (Oxford, UK: Oxford University Press), 221–240.

Morse, D. R., Martin, J. S., Furst, M. L., and Dubin, L. L. (1977). A physiological and subjective evaluation of meditation, hypnosis, and relaxation. *Psychosom. Med.* 39, 304–324. doi: 10.1097/00006842-197709000-00004

Nuys, D. V. (1973). Meditation, attention, and hypnotic susceptibility: a correlational study. *Int. J. Clin. Exp. Hypn.* 21, 59–69. doi: 10.1080/00207147308409306

Oakley, D. A., and Halligan, P. W. (2013). Hypnotic suggestion: opportunities for cognitive neuroscience. *Nat. Rev. Neurosci.* 14, 565–576. doi: 10.1038/nrn3538

Parris, B. A. (2017). The role of frontal executive functions in hypnosis and hypnotic suggestibility. *Psychol. Conscious. Theory Res. Pract.* 4, 211–229. doi: 10.1037/cns0000106

Pekala, R. J. (1991). "The phenomenology of consciousness inventory," in *Quantifying Consciousness*, eds C. E. Izard, and J. L. Singer (New York, NY: Springer), 127–143. doi: 10.1007/978-1-4899-0629-8_8

Pekala, R. J., and Creegan, K. (2020). States of consciousness, the qEEG, and noetic snapshots of the brain/mind interface: a case study of hypnosis and sidhi meditation. *OBM Integr. Complement. Med.* 5, 019. doi: 10.21926/obm.icm.2002019

Raffone, A., and Srinivasan, N. (2010). The exploration of meditation in the neuroscience of attention and consciousness. *Cogn. Process.* 11, 1–7. doi: 10.1007/s10339-009-0354-z

Raz, A., and Lifshitz, M. (2016). *Hypnosis and Meditation: Towards an Integrative Science of Conscious Planes*. Oxford, UK: Oxford University Press.

Rosenthal, D. (2005). *Consciousness and Mind*. Oxford, UK: Oxford University Press.

Sadler, P., and Woody, E. (2010). "Dissociation in hypnosis: theoretical frameworks and psychotherapeutic implications," in *Handbook of Clinical Hypnosis*, eds S. J. Lynn, J. W. Rhue, and I. Kirsch (Washington, DC: American Psychological Association), 151–178. doi: 10.2307/j.ctv1chs5qj.10

Semmens-Wheeler, R., and Dienes, Z. (2012). The contrasting role of higher order awareness in hypnosis and meditation. *J. Mind Body Regulat.* 2, 43–57.

Smallwood, J., and Schooler, J. W. (2015). The science of mind wandering: empirically navigating the stream of consciousness. *Ann. Rev. Psychol.* 66, 487–518. doi: 10.1146/annurev-psych-010814-015331

Spanos, N. P., Rivers, S. M., and Gottlieb, J. (1978). Hypnotic responsivity, meditation, and laterality of eye movements. *J. Abnorm. Psychol.* 87, 566. doi: 10.1037/0021-843X.87.5.566

Spanos, N. P., Stam, H. J., Rivers, S. M., and Radtke, H. L. (1980). Meditation, expectation and performance on indices of nonanalytic attending. *Int. J. Clin. Exp. Hypn.* 28, 244–251. doi: 10.1080/00207148008409849

Swain, N. R., and Trevena, J. (2014). A comparison of therapist-present or therapist-free delivery of very brief mindfulness and hypnosis for acute experimental pain. *New Zeal. J. Psychol.* 43, 22.

Tellegen, A., and Atkinson, G. (1974). Openness to absorbing and self-altering experiences ("absorption"), a trait related to hypnotic susceptibility. *J. Abnorm. Psychol.* 83, 268. doi: 10.1037/h0036681

Terhune, D. B., Cleeremans, A., Raz, A., and Lynn, S. J. (2017). Hypnosis and top-down regulation of consciousness. *Neurosci. Biobehav. Rev.* 81, 59–74.

Terhune, D. B., and Jamieson, G. A. (2021). Hallucinations and the meaning and structure of absorption. *Proc. Natl. Acad. Sci. U.S.A.* 118, e2108467118. doi: 10.1073/pnas.2108467118

Tung, Y.-H., and Hsieh, J.-C. (2019). The impacts of mindfulness on heart rate variability: a brief review. *Int. J. Pharma Med. Biol. Sci.* 8, 132–137. doi: 10.18178/ijpmbs.8.4.132-137

Walrath, L. C., and Hamilton, D. W. (1975). Autonomic correlates of meditation and hypnosis. *Am. J. Clin. Hypn.* 17, 190–197. doi: 10.1080/00029157.1975.10403739

Williams, R. M., Day, M. A., Ehde, D. M., Turner, A. P., Ciol, M. A., Gertz, K. J., et al. (2022). Effects of hypnosis vs mindfulness meditation vs education on chronic pain intensity and secondary outcomes in veterans: a randomized clinical trial. *Pain*. doi: 10.1097/j.pain.0000000000002586

Zeidan, F., and Grant, J. A. (2016). *Meditative and Hypnotic Analgesia: Different Directions, Same Road?* Oxford, UK: Oxford University Press.

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The *why* of the phenomenal aspect of consciousness: Its main functions and the mechanisms underpinning it

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What distinguishes conscious information processing from other kinds of information processing is its phenomenal aspect (PAC), the-what-it-is-like for an agent to experience something. The PAC supplies the agent with a sense of self, and informs the agent on how its self is affected by the agent's own operations. The PAC originates from the activity that attention performs to detect the state of what I define "the self" (S). S is centered and develops on a hierarchy of innate and acquired values, and is primarily expressed via the central and peripheral nervous systems; it maps the agent's body and cognitive capacities, and its interactions with the environment. The detection of the state of S by attention modulates the energy level of the organ of attention (OA), i.e., the neural substrate that underpins attention. This modulation generates the PAC. The PAC can be qualified according to five dimensions: qualitative, quantitative, hedonic, temporal and spatial. Each dimension can be traced back to a specific feature of the modulation of the energy level of the OA.

KEYWORDS
information, phenomenal aspect of consciousness (PAC), attention, energy, the self (S), organ of attention (OA)

Introduction

Various different theories try to explain the underlying mechanisms of consciousness (for recent reviews, see Northoff and Lamme, 2020; Winters, 2021). One of the most promising approaches that is fully adopted or partly shared by some of these theories is to investigate consciousness in informational terms. Chalmers (1996, pp. 285–287) explicitly theorized that information can be a good construct to make the link between physical processes and conscious experience. Since then, the idea that consciousness can be investigated in informational terms, has been recurrently put forward both in scientific research and philosophical debates (Tononi, 2008, 2012; Aleksander and Gamez, 2011; Earl, 2014; Jonkisz, 2015, 2016; Tononi and Koch, 2015; Fingelkurts and Fingelkurts, 2017; Orpwood, 2017; Ruffini, 2017; Marchetti, 2018; Kanai et al., 2019; but some researcher had adopted this idea even before Chalmers' proposal: see Baars, 1988).

While generally supported by theoretical considerations concerning the nature of life[1], this approach is not exempt from criticism, above all for its panpsychist implications (see for example Pockett, 2014).

I endorse such an approach as my starting point, but I maintain that not all kinds of information processing are conscious: after all, there is ample evidence of information processed by humans unconsciously, as well as of not-conscious information processed by computers. Consciousness is a phenomenon that evolved by purely biological processes on a planet where it did not exist previously (and that, once appeared, can theoretically also be artificially replicated).

Given this, the fundamental question to be addressed is what distinguishes conscious information processing from other kinds of information processing.

The answer is to be found in what primarily distinguishes consciousness from other phenomena: the qualitative, *phenomenal aspect of consciousness* (from here on: PAC), i.e., the what-it-is-like for an agent to experience something. Taking the PAC into consideration, what it adds to information processing[2], and, above all, what difference it makes to the agent that is processing information, allows one to understand what distinguishes conscious information processing from other kinds of information processing. Ultimately, this means explaining the *why* of the PAC: why it is needed for an agent and why it has the form it has.

It can certainly be argued that the difference between conscious information processing and other kinds of information processing can also be found somewhere else than in the PAC, for example, in the specific organization and functioning of the brain as compared to the organization and functioning of systems performing a different kind of information processing (Fingelkurts et al., 2010, 2013; Rabinovich et al., 2012; Fingelkurts and Fingelkurts, 2017).

According to Fingelkurts and Fingelkurts (2017, p. 2), the brain is "an active system that retains the characteristics of a complex, non-linear system with non-equilibrium dynamics, reflected in transient evolution of transient states in the form of discrete frames of activity and phase transitions between micro- and macro-levels." As such, the information processed by the brain is characterized by self-organization, the interplay of stability/instability, timing of sequential processing, coordination of the multiple sequential streams, circular causality between bottom–up and top–down operations, and information creation, all aspects that cannot be captured by the classical Shannonian concept of information. Consequently, the information processed by the brain (as opposed to the information processed by other systems) can be described as "ordered sequences of metastable states across multiple spatial and temporal scales." In a similar vein, Rabinovich et al. (2012, pp. 51, 60) maintain that "brain flow information dynamics deals with problems such as the stability/instability of information flows, their quality, the timing of sequential processing, the top–down cognitive control of perceptual information, and information creation" and consequently that a cognitive (mental) information flow can be defined as "a flow along a chain of metastable states."

I think that distinguishing conscious information processing from other kinds of information processing on the basis of the organization and functioning of the brain certainly offers an important contribution to the explanation of salient aspects of consciousness, such as the stream of consciousness and how the brain creates new information. However, without a preliminary analysis of the PAC, of the difference it makes for information processing and for the agent processing it, one can hardly capture the core difference between conscious information processing and other kinds of information processing: after all, what primarily distinguishes consciousness from all other phenomena is its qualitative, phenomenal aspect. Moreover, one must also take the PAC into consideration whenever one wants to deal with the other features of consciousness (such as the stream of consciousness or the unity of a conscious state): in fact, it is principally on the basis of the PAC that one can identify these features.

Following Chalmers (1995), it can also be argued that the way in which I tackle the problem of the PAC (that is, by relating the PAC to the agent: "What difference does it make to the agent that is processing information?") will never help solve the hard problem of consciousness ("Why and how do physical processes in the brain give rise to experience?") because phenomenal consciousness and states are not relational phenomena (they cannot be functionally defined) but intrinsic ones (Di Francesco, 2000). I think that the distinction between the hard problem of consciousness and the easy problem of consciousness is misleading because it creates a break where there is none. Phenomenal consciousness and conscious phenomena are such simply because there is an experiencing subject (the agent) who experiences them, and to whom they make a certain difference (that is, they have a certain meaning for the experiencing subject). An experience without its experiencing subject is no longer an experience: it loses its meaning. As Nida-Rümelin (2017, p. 56) observes: "we cannot even think the occurrence of an experience without thereby thinking of it as involving an experiencing subject." The experience of pain is such because there is an experiencing subject who experiences it: without the experiencing subject, there will be only an empty, abstract concept – the concept of "pain" – but no actual experience

1 Information has been considered a fundamental dimension of living beings (Roederer, 2003; Nurse, 2008; Skyrms, 2010; Farnsworth et al., 2013; Walker and Davies, 2013; Adami, 2015; Baluška and Levin, 2016), if not actually the fundamental dimension that distinguishes living beings from other entities. For example, Skyrms (2010, p. 32) states that: "it is the flow of information that makes all life possible."

2 I use "information processing" in a very general sense here, which includes all the various operations that can be performed on and with information, such as generation, encoding, decoding, management, storage, transduction and transmission of information.

of pain. When I say that I have toothache, you can certainly understand what I mean, but you cannot feel my toothache (or, said otherwise, you experience the meaning of the word "toothache" but you do not experience any toothache). In sum, the problem of the PAC can only be solved by also taking its experiencing subject into account[3].

Therefore, in this article I aim principally at answering the question of the *why* of the PAC, that is, the difference that it makes for the agent that processes information. I will then offer a tentative explanation of the mechanism that underpins the PAC. For reasons of space, I will not deal with higher forms of consciousness, such as meta-cognitive consciousness. Suffice it to say that most arguably these higher forms of consciousness are made possible by, and develop on, the more basic form of phenomenal consciousness, once reflective self-awareness has formed (Gallagher and Zahavi, 2008).

Current research on consciousness deals principally with the *how*, not with the *why* of the phenomenal aspect of consciousness

Generally speaking, two main approaches are adopted when analyzing consciousness in informational terms. The most common one is to take the PAC for granted, without directly investigating its *why,* that is, its role in an agent's processing of information. For example, Ruffini (2017, p. 2) clearly states: "We do not address here the *hard problem* of consciousness – the fundamental origin of experience (. . .) We assume that *there is consciousness*, which, with the right conditions, gives rise to structured experience". Likewise, Kanai et al. (2019, p. 2) maintain that "Instead of directly addressing the Hard problem, a possibly more productive direction might be to consider putative functions of consciousness, namely, cognitive functions that require consciousness in the sense of being awake and able to report stimulus contents with confidence."

This approach primarily investigates the *how* of consciousness, that is, what structures bring it about, such as the neural correlates of consciousness (NCC) (e.g., Baars, 1988; Mashour et al., 2020) and the brain's internal models of the environment that allows agents to simulate the consequences of their own or other agents' actions and avoid dangerous outcomes (e.g., Ruffini, 2017; Kanai et al., 2019). This approach also focuses on the possible functions that consciousness may have in supporting the other cognitive functions (e.g., the executive one). However, strangely indeed, the functions of consciousness are mostly considered and explained independently of the PAC. Even when somehow relating the function of consciousness to the PAC, scholars adopting this approach do not consider the role that the PAC plays in processing information. For example, various scholars claim that consciousness has the function of making information globally available across the system, and transforming data into a *format* that can be easily and flexibly used by high-level processors (language, autobiographical memory, decision-making, metacognition, etc.) (Baars, 1988; Dehaene and Naccache, 2001; Earl, 2014; Mashour et al., 2020; Frigato, 2021). However, they do not explain why this must be the case, that is, why only information and data that have the particular phenomenal aspect that consciousness assigns to them, can be made globally available across the system and processed by high-level processors. Kanai et al. (2019, p. 6), in their "information generation" model of consciousness, recognize the importance of the PAC when they observe that it allows for distinguishing representations of factual reality of the here and now from counterfactual representations (e.g., past and future events), because the former are more vivid than the latter. They also explain that the difference in vividness of experience comes from the difference in the degree of details produced by the generative model that they have postulated. However, they completely skip the essential question: Why is the PAC needed to distinguish representations of factual reality from counterfactual representations? Could an agent not make such distinctions unconsciously? What does experience (of vividness as well as of anything else) do that the lack of experience cannot do?

The second kind of approach does try to account for the PAC, but, similarly to the first, it focuses mostly on the *how* of conscious experience instead of the *why*. Therefore, this approach is not of great help either in explaining the role that the PAC plays in an agent's processing of information, as well as in differentiating conscious information processing from other kinds of information processing. As an example of this kind of approach, let's briefly consider the Integrated Information Theory of consciousness (IIT) put forward by Tononi (2008, 2012), Oizumi et al. (2014), and Tononi and Koch (2015). IIT directly tackles the PAC: it firstly identifies the main phenomenological properties of consciousness, what IIT defines as "axioms": intrinsic existence, composition, information, integration and exclusion. Then it derives a set of "postulates" that parallel the axioms and specify how physical systems might realize these axioms. Last, it develops a detailed mathematical framework in which the phenomenological properties are defined precisely and made operational. IIT defines consciousness as integrated information (Φ), where integrated information stands for the amount of information generated by a complex of elements, above and beyond the information generated by its parts.

3 For a similar view, see Safron (2020, p. 22): "If *cognition* is primarily discussed in the abstract, apart from its embodied–embedded character, then it is only natural that explanatory gaps between brain and mind should seem unbridgeable."

The choice of IIT to limit the investigation of consciousness to its phenomenological properties limits IIT's possibilities to explain the role that the PAC plays in an agent's processing of information. IIT considers the phenomenological properties of consciousness in themselves, without any connection to the possible cognitive functions they can have (such as planning and initiation of behavior). This choice, which has led Cerullo (2015) to define IIT as a theory of "protoconsciousness" or "non-cognitive consciousness" (as opposed to a theory of "cognitive-consciousness"), makes IIT tackle a kind of consciousness that substantially differs from the one tackled by psychology, cognitive neuroscience and neurology. While the latter is supposed to have evolved in association with the other cognitive functions of the system (such as memory and attention) in order to assist the system in controlling its own behavior, the former does not necessarily imply a functional role for the system's behavior, and lacks the cognitive properties associated with such a role. Indeed, IIT does not intend to explain why, to what purpose a system should generate phenomenal consciousness. Rather, IIT intends to explain how the generation of integrated information leads to the PAC. In sum, this limits IIT's possibilities to account for the possible functions of the PAC, as well as for the functions of the other cognitive functions of the system (memory, attention, etc.) associated with the PAC.

A related argument has been put forward by Safron (2020), according to whom most of IIT's problems originate from the fact that IIT does not take the agent's interactions with the world into consideration ("Without those meaningful external connections, systems could have arbitrarily large amounts of integrative potential, but there still may be nothing that it is like to be such system," Safron, 2020, p. 16). In Safron's view, the minimal condition for a system to be conscious is that it is capable of generating, from an egocentric perspective, integrated system-world models with spatial, temporal, and causal coherence, all of which require agentic, autonomous selfhood. Consequently, he suggests integrating IIT (and GNWT) with the Free Energy Principle and Active Inference Framework (FEP-AI) (Friston et al., 2006, 2017), which provides a formalism of how internal states can model external states. While I agree with Safron in that, in order to deal with consciousness, it is necessary to take the system's interactions with the world into account (see my discussion on the sense of self in the section "Why is the phenomenal aspect of consciousness needed?"), I think that FEP-AI, albeit being useful in defining how a system's internal states can model external states, is of limited utility in explaining the basis on which the distinction between the system (or self) and the world takes place. As Di Paolo et al. (2022, p. 28) explain, FEP-AI presupposes such a distinction, instead of explaining it: "All processes subserving self-distinction are themselves products of self-production. In contrast, Markov blankets in FEP systems are there by assumption (. . .) there is nothing in the Markov Blanket that necessarily links it to processes of organismic constitution." As it will become clear later in the article, in order to account for the basis of the system-world distinction, it is necessary to consider the attentional mechanism underlying the hedonic dimension of the PAC.

The integrated information theory of consciousness has also raised some other criticisms because of its identification of consciousness with integrated information. Taken to extremes, this identification leads one to maintain that any system that has integrated states of information is conscious (Cerullo, 2015; Jonkisz, 2015), which implies some counterintuitive consequences, such as the attribution of consciousness to simple artifacts, such as photodiodes.

Moreover, as Mudrik et al. (2014) show, there are at least four integrative processes that occur without consciousness, that is, short-range spatiotemporal integration, low-level semantic integration, single sensory (versus multisensory) integration, and previously learned (versus new) integration. Therefore, information integration, even if it turns out that it is most probably necessary for consciousness, is not sufficient.

Finally, Mindt (2017) observes that, even though IIT can provide a detailed account of how experience might arise from integrated information, it nevertheless leaves open the question of why it feels like something for a brain to integrate information.

Similar to IIT, the theory put forward by Orpwood (2017) also tackles directly the PAC. Orpwood argues that qualia are a likely outcome of the processing of information in local cortical networks: qualia would arise when attention or some other re-entrant processes develop an attractor state in a network that enables the network to identify the information cycled (at least, three times) through it as a representation of the identity of its previous input. However, Orpwood does not explain why, to what purpose, consciousness is required to perform such an identification process: could such an identification not occur without the support of consciousness?

It is anyhow important to note that, despite their inability to explain the why of the PAC, the majority of theories developed within these two approaches do provide powerful tools in the scientific study of consciousness, both in terms of their predictive capacity, testability and possibility of carrying out precise measures. For example, GNW (Global Neuronal Workspace) (Mashour et al., 2020, p. 789) very clearly predicts that consciousness can be disrupted when the function of cortical hubs or reverberant connectivity is disrupted.

Why is the phenomenal aspect of consciousness needed?

Let's now try to answer the fundamental questions about the PAC.

To begin with: what difference does the PAC make in general? No doubt, the PAC makes experience appear as it is – that is, an "experience" – and makes it differ from other experiences: it makes factual reality appear what it is – that is, "real" – and makes it differ from dream; it makes pain appear as "painful" or "hurting" and pleasure as "pleasant"; it makes pain differ from pleasure, and a big pain differ from a small pain.

But why is the PAC needed at all? As the philosopher Campbell (2011, p. 323) asked: "Why should *experience* be needed? Why not just any way of being causally impacted by the events around us, in a way that gives information about them?" Could we not do without experience and process the information unconsciously? After all, much – if not the majority - of what happens inside our brain, happens without our knowledge.

My answer is that *the information provided by the PAC supplies the agent with a sense of self, and how this self is affected by the agent's own operations*[4].

Let's clarify how the terms "operation," "information," "sense of self," and "affected" must be understood.

By "operations" (and "operate") I refer in a very general sense to the various physical and mental activities that an agent performs, either on an active, voluntary, goal-directed basis (e.g., walk, eat, speak) or on a passive, involuntary, stimulus-driven one (e.g., dream, involuntarily move in response to a stimulus, perceive pain, feel hungry or thirsty).

By "information" (and "inform") I do not refer to a "universal" kind of computation, according to which information can be programmed in, and represented by any abstract symbols, but rather to a "fixed" kind of computation, according to which the hardware and software are interdependent, and information is instantiated in the form of the structure (Farnsworth et al., 2013). While in the former kind of computation, information can be instantiated by any program, code and physical system, in the latter (which is typical of living systems), information can only be instantiated by the specific biological system (or agent) that embodies it. This has three important implications. The first is that the agent does not need at all to decode, translate or transduce the message of the PAC into any other language: the agent immediately grasps the message of the PAC by experiencing it, because what the PAC means, its content, coincides with the form (the aspect) of the PAC (Marchetti, 2018). This happens even when the message is ambiguous, lacks sufficient clarity or just provides a very general feeling, such as that of rightness or familiarity: in fact, in such cases, the meaning conveyed by the conscious experience is precisely of "ambiguity," "not sufficiently clear," "familiarity," etc.[5] The second implication is that the precise meaning that the information provided by the PAC has for the agent that experiences it, can only be understood by the agent itself and not by another agent: in other words, I know what it means for me to experience "pain," but another person cannot directly know what it means for me to experience "pain" (and vice versa). This is because the information provided by conscious experience is always "individuated" – to use Jonkisz's (2015) expression –, that is, it is shaped by the agent's evolutionary antecedents and by its unique and particular interactions with its environment and other agents. The third implication is that the information provided by the PAC cannot be adequately dealt with by every theory of information. This is because the PAC is derivative on an experiencing subject who produces and interprets it. Therefore, those theories of information - such as Dretske (1981), Floridi (2005), and Mingers and Standing's (2014) – which maintain that information is fundamentally objective and exists independently of the agent that produces it, cannot adequately account for the information provided by the PAC. A more suitable theory of information seems to be Hofkirchner's (2013, 2014) unified theory of information (UTI), because it shows how (self-organizing) systems produce information. According to Hofkirchner (2013, p. 9), information is produced when "self-organizing systems relate to some external perturbation through the spontaneous build-up of order they execute when exposed to this perturbation." Self-organizing systems produce information because they transform the input into an output in a non-deterministic and non-mechanical way. On the contrary, computers, probabilistic machines and other systems that compute and work according to strict deterministic rules, which by definition do not yield novelties, cannot produce information (Hofkirchner, 2011). Hofkirchner's definition of information production can be equated with Bateson's (1972) famous definition of information as a "difference which makes a difference." Bateson's "making a difference" is the build-up of the system's self-organized order; Bateson's "difference" that makes a difference is a perturbation in the inner or outer environment of the system that triggers the build-up; Bateson's "difference that is made" is made to the system because the perturbation serves a function for the system's self-organization.

The "sense of self" can be described as characterized by the following fundamental features: (a) the sense of being an entity differentiated from other entities. This provides the agent with a sense of mineness or ownership, that is, the quality that all its experiences belong to, and are for it (and not for-someone-else); (b) what can be defined as the "point of view" from which any content is "seen". This point of view persists through all conscious experiences independently

4 For the first part of the answer ("the PAC supplies the agent with a sense of self"), I have drawn upon Damasio's (1998, 1999, 2010) work. See for example Damasio (1998, p. 1880): "what we must explain if we are to address the issue of consciousness is the generation of a sense of self and the generation of the sense that such self is involved in the process of perceiving the stimulus."

5 As Mangan (2001) shows, these kinds of conscious experiences serve precise purposes. For example, the feeling of familiarity signals that what we are experiencing now has been encountered before.

of their contents (Winters, 2021, p. 12) and partitions the world into the asymmetric space of what monitors and what is monitored (Merker, 2013a,b); (c) a feature that is strictly associated with the "point of view": the feeling of continuity. Our experience flows uninterruptedly like a river. As James (1890/1983, pp. 233–234) observed: "the transition between the thought of one object and the thought of another is no more a break in the thought than a joint in a bamboo is a break in the wood." The feeling of continuity is assured even when there are temporary interruptions in conscious experience (because of sleep, anesthesia, etc.): indeed, these interruptions are not experienced directly as such, that is, as gaps of consciousness, but indirectly, as conscious experiences of having lost consciousness. As Evans (1970, p. 185) observed : "It is only by inference that we know that we have been unconscious, or by being told of this by someone else." That is, the sense of self acts like an uninterrupted, permanent background on which specific, separated contents follow one another, and changes can be perceived; (d) last but not least, the capacity it has to represent an organism composed of multiple, interconnected parts in the unified and condensed way of a "single voice" (Damasio, 2010), that is as a single unit. This allows the agent to devise plans and actions that best fit its existence as a whole, rather than favoring some of its parts to the detriment of the other ones, and coordinate its behavior accordingly: in a word, to maintain and expand the well-being of the agent in its entirety.

It could be claimed that exceptional conscious states – such as those induced by drugs or meditation, and pathological conscious states – may lack some of the features that a sense of self implies (e.g., spatial self-location, mineness), if not all of them. After all, these states often present a phenomenology that substantially differs from the phenomenology of ordinary conscious experience. Consider, for example, the alleged cases of self-loss or ego-dissolution reported by highly experienced mindfulness meditators: "it's like falling into empty space... and a sense of dissolving [...] there's no personal point of view, it's the world point of view, it's like the world looking, not [me] looking, the world is looking" (Millière et al., 2018, p. 11), or by users of psychedelic drugs: "I wasn't anything anymore. I had been broken down into nothingness, into oblivion" (Millière et al., 2018, p. 16). However, as Gallagher (2017, p. 5) argues, it is not at all clear how one can even report on these extreme states of consciousness without having registered them as one's own (and not as someone's else). To this argument, I further add that it does not matter whether the "one" these states refer to or are for, is myself, the world, the universe, everything or nothing, or whether this "one" implies a perspective centered onto a single point of origin inside myself rather than a perspective from everywhere or nowhere, or whether this "one" is embodied or fully disembodied. Actually, to be able to say that "I was the universe, I was everywhere and nowhere" or "(I forgot) that I was a male, a human, a being on Earth—all gone, just infinite sensations and visions" (reported by Millière et al., 2018), one must have been aware, while experiencing those extreme experiences, that they were experienced by oneself, whatever "oneself" or "I" refers to at the time of the experiences. Therefore, in my view, it is legitimate and safer to conclude that consciousness always implies at least a minimal level or form of self, even if some of its features can be missing.

With the term "affected" I refer not so much to the (more or less) permanent modifications that take place *after* the agent has experienced something and that are usually identified with "memories" and what was "learnt." Nor do I generally refer to whatever (physical, chemical, etc.) changes may occur inside the agent's organism. Rather, I specifically refer to the temporary effects that an agent's given operation has on the agent's *self*, that is, at the level that – by summarizing the complexity inherent to the composite structure of the agent's organism – represents and stands for the agent in its entirety as a single unit. Most frequently, these effects imply a (temporary) variation in the state of the self, but sometimes they may imply no variation. This is reflected in our languages by verbs and nouns that allow us to express the conscious experience of a lack of change, and say for example that "we noted no differences," or that "nothing happened" (for the sake of simplicity, we can use the term "variation" to generally refer to the effects that an agent's operation has on the agent's self, irrespectively of whether they imply a variation or not).

As an example of the possible effects that the agent's operations have on its *self*, consider the experience of pain. This experience, metaphorically speaking, "tells" the agent that it is undergoing a specific variation that affects it as a whole, as a single unit, and that this variation is characterized by a certain intensity and a certain hedonic aspect that distinguish it from other types of variations. For example, the variation that the agent undergoes when it feels pain has an opposite hedonic aspect compared to pleasure: while the former acts as a "block" that forces the agent to operate in a different way (so as to remove the cause of the pain), the latter "sustains" the agent's activities, leading it to keep on doing what it's doing.

In their essence, these temporary variations represent the impact that the agent's own (voluntary or involuntary) operations (such as perceiving, moving, thinking, remembering, dreaming, speaking, etc.) have on the agent's self. They provide the agent with the direct, immediate and intuitive knowledge (on which rational knowledge can subsequently be built and developed) of how entities and events in general *relate* to the agent's self: for example, how a certain object limits or facilitates the agent's activity, how the agent can modify or use it, where the object is spatially located relative to the agent, etc. It is precisely these temporary variations that the agent's self undergoes because of the entities and events with which the agent enters into relation, that allow the agent to define, represent, identify and recognize them.

In relation to this aspect, it is important to highlight that these temporary variations allow the agent to progressively build its personal knowledge not only about the entities and events it comes upon, but also about itself. Actually, as it has been observed (Rochat, 2003; Cleeremans, 2008; Ciaunica et al., 2021), the sense of self is not just given, but must be learnt and achieved: it emerges from the continuous process of differentiation between the agent and the other entities. It seems very plausible that, at least for humans, this differentiation process already starts *in utero*. The evidence reviewed by Ciaunica et al. (2021) shows that prenatal organisms possess a basic form of self-awareness. For example, fetuses spend a considerable amount of time in tactile exploration of the boundary between innervated and non-innervated areas. According to Ciaunica et al. (2021, p. 7), this demonstrates that "The fetus is thus exploring the boundaries of his or her self, developing knowledge of the effects of his or her own self-generated action, and its consequences."

It must be further noted that the sense of self is not always explicitly experienced by the agent. Actually, most of the time when we experience something, we are not self-aware of it: we simply experience it without having the additional, explicit experience that it is we who are experiencing it. This does not mean however that on these occasions the sense of self is absent: in fact, it is present, but in a "pre-reflective" form. As it has been argued (Legrand, 2006, 2007; Gallagher and Zahavi, 2008), it is possible to distinguish between two forms of self-awareness: pre-reflective self-awareness and reflective self-awareness. The former is intrinsic, tacit, non-observational (i.e., not implying an introspective observation of oneself) and non-objectifying (i.e., it does not turn one's experience into an observed object). The latter is explicit, observational and objectifying: it introduces a form of self-division or self-distancing between the reflecting and the reflected-on experience. Pre-reflective self-awareness is the constitutive structural feature of any conscious state: as such, it exists independently of reflective self-awareness; on the contrary, reflective self-awareness always presupposes pre-reflective self-awareness. Evidence shows that every conscious mental state always involves pre-reflective self-awareness: (i) as remarked by Husserl (1989, p. 18a), each thing that appears has *eo ipso* an orienting relation to us, even if we are just imagining it (if we are imagining a centaur, we cannot help but imagine it as in a certain orientation and in a particular relation to our sense organs); (ii) it is always possible for us to return to an experience we had and remember it as our experience, even if originally we did not live it explicitly as "our" experience. This would not be possible if the experience were completely anonymous, that is, lacking the property of intrinsically belonging to us; (iii) all our conscious experiences are given immediately as ours: we do not first have a conscious experience and only later the feeling or inference that it was ours!

Finally, it should be observed that the explanation I have put forward of the need of the PAC ("the PAC provides the agent with a sense of self, and informs it on how the self is affected by its own operations"), subsumes and can easily explain many of the answers that researchers and scholars have provided about the functions of consciousness, even if these answers were not originally intended to account for the functions of consciousness in terms of the PAC (see, for example, Baars, 1988; Morsella, 2005; Frith, 2010; Campbell, 2011; Earl, 2014; Keller, 2014; Pierson and Trout, 2017; Kanai et al., 2019). Let's consider some of the most representative answers.

A very plausible answer by Kanai et al. (2019) is that experience has the function of internally generating "counterfactual representations" of events, that is, representations detached from the current sensory input, which enable one to detach oneself from the environment, simulate novel and non-reflexive behavior, plan future actions, and learn from fictional scenarios that were never experienced before. Similarly, for Earl (2014, pp. 13–14), organisms that possess only automatic responses may sometimes have no response to match a situation that confronts them, which could result in a missed opportunity or a risk to the organism; therefore, a mechanism, of which consciousness is a key component, has evolved to generate responses to novel situations. However, neither Kanai et al. (2019) nor Earl explain why only representations provided with the particular phenomenal aspect that consciousness assigns to them, allow us to simulate new behaviors and scenarios, plan future actions, etc. They only tautologically state that experiencing counterfactual representation allows you to experience new behaviors and scenarios, future plans, etc. The explanation I have provided, on the contrary, accounts for this by showing that one can simulate new behaviors and scenarios, etc., only if one can see the effects that these simulations have on oneself as a single unit, as a "single voice," which primarily happens via the temporary changes one undergoes as a whole while mentally performing the simulations.

Another recurrent and plausible answer is that experience is adaptive (James, 1890/1983; Morsella, 2005; Earl, 2014). It is not a case that we developed unpleasant feelings toward what harms us and pleasant feelings toward what is good for us. If experience had no function at all, we could quite easily have developed unpleasant feelings toward what is good for us and pleasant feelings toward what harms us. More in general, if consciousness had no effects on behavior, it would not matter if our experiences were completely fantastical and had no correlation with reality (Earl, 2014, p. 7). However, scholars do not explain why just experience has this adaptive capacity, and leave the explanation to the reader's intuition. My explanation, on the contrary, provides an answer to this question. Unpleasant feelings bring their action to bear on our behavior by inducing a temporary change in us that blocks us, in our wholeness, from doing what we are doing, and forces us to operate differently. In a similar but opposite way, pleasant feelings bring their action to bear on our behavior by inducing a temporary change in us that makes us continue to do what we were doing.

Morsella (2005) also provides another possible answer when he notes that the skeletal muscles - though often functioning unconsciously - are the only effectors that can be controlled directly via conscious processes. He argues that phenomenal awareness is needed to resolve conflicting, parallel impulses and cognitive processes in order to produce coordinated single actions by means of the skeletomotor system. In this view, consciousness acts as a forum that allows for information from different sources to interact in order to produce adaptive actions. Without consciousness, "the outputs of the different systems would be encapsulated and incapable of collectively influencing action" (Morsella, 2005, p. 1012). But why does just consciousness have this capacity to act as a forum? Morsella does not explain this. It is clear that Morsella's argument rests on the presupposition that whatever impulse for whatever reason enters the forum of consciousness, is able to affect the agent in its entirety, not just a part of it. This can be realized only if there is a processing level that stands for the agent in its entirety and that allows the agent to understand the effect that the impulse has on it as a whole, which is precisely what my explanation suggests.

The mechanisms that underpin the phenomenal aspect of consciousness

What is the mechanism that supports conscious information processing? According to my analysis (Marchetti, 2018), conscious information processing is made possible by two fundamental components: attention and what I have defined "the self" (from now on: S). Furthermore, a special role in the formation of complex forms of conscious experience is played by a sub-component of S: working memory (WM). These components are individually necessary and jointly sufficient for an agent to be conscious: taken individually, S and attention are fundamental parts of a conscious agent, but are not the same as a conscious agent considered in its entirety.

The self (S)

S originates from the agent's organism and comprises the agent's body and brain (excluding attention and its organ): it is primarily expressed via the central and peripheral nervous systems, which map the agent's body, environment, and interactions with the environment (Marchetti, 2018). It embodies all the competencies and abilities – physical, social, linguistic, and so on – the agent innately possesses and acquires in its life (at the end of which, S ceases to exist).

Besides providing the physical and material basis for all the agent's organs, S supplies the *contents* of phenomenal experience: perceptible ones, such as "yellow" and "cat," as well as intangible ones, such as memories, ideas, and emotions.

S runs the organism according to a fundamental principle or goal, which governs all the other principles: to stay alive. Operationally, the principle can be expressed as follows: "operate in order to continue to operate" (Marchetti, 2010). This is the vital instinct, the algorithm of life, which is already present in the simplest cell (Damasio, 2010).

This principle is primarily instantiated in a hierarchy of values, among which the biological ones (e.g., homeostasis) play a pivotal and foundational role. On these values other kinds of values (e.g., cultural) can be developed during the agent's life. These values define what is relevant and meaningful for the agent, and guide the development of S.

The development of S occurs as a consequence of the agent's activity, namely its interaction with the (natural and social) environment. The agent's activity and its outcomes are mapped by the brain, which leads to a continuous modification of S. This process is differently described and termed by scholars: see for example Baars's (1988) creation of new unconscious contexts, Edelman's (1989) reentrant mechanisms, which allows for categorization and learning, and Damasio's (1999) formation of first- and second-order brain maps.

S helps maintain and expand the well-being of the agent in its entirety: it provides a sufficiently stable platform and source of continuity relative to the outside world. As highlighted by Damasio (2010, p. 200), the working of its more or less stable parts (internal milieu, viscera, musculoskeletal system, etc.) constitutes an "island of stability within a sea of motion. It preserves a relative coherence of functional state within a surround of dynamic processes whose variations are quite pronounced."

This "island of stability" is made possible mainly by the values on which S is centered: it represents the central, (almost) unchanging core of S that assures the continuity of the organism (and ultimately of the agent) across the various modifications that it can undergo. Moreover, this "island of stability" acts as a reference point that allows for the detection (by attention) of the relevant changes of the state of S that are occasioned by the agent's activity and by the inner processes of the organism. The detection of these changes allows the agent to promptly react, according to the relevance they have for it. By means of the agent's activity, the homeostatic range associated with well-being can thus be reestablished.

As I said before, S supplies the contents of phenomenal experience. But does consciousness actually require any content in order to occur? It could be argued that content is not a necessary condition for consciousness. With regard to this issue, various scholars (Thompson, 2015; Millière et al., 2018; Josipovic and Miskovic, 2020; Srinivasan, 2020) have reported cases of conscious experience of reduced or even absent phenomenal content. These cases can occur in several situations: when transitioning to and from sleep, when waking from anesthesia, under the influence of psychedelics, and during meditation. These cases seem to call into question the necessity of content for consciousness (but not of S, because S provides all the necessary material support for consciousness). However, upon a closer look, this conclusion turns out to be a bit premature. Let's consider for example the contentless experience that marks the first instant of awakening: it is true that the only thing one feels is to be alive in the present moment (sometimes one does not even know who one is or where one is), but it is equally true that upon having it, one is automatically and unavoidably led to the more common kind of experience-with-content ("I am in my bedroom") that characterizes daily life. This seems to indicate that experience-with-content is the unavoidable and unescapable default conscious state, and that experience-without-content is just a temporary, intermediate form of consciousness.

A final remark about the adequacy of my definition of S. As it is known, there is not much consensus on a common definition of the self. Various scholars and philosophical schools adopt different definitions of the self (Di Francesco and Marraffa, 2013; Facco et al., 2019). If we consider just the Western tradition, we can see a range of definitions that goes from those that deny the existence of the self – such as Hume (1739/1985), who claimed that the self is just a fictional entity, or Dennett (1991), for whom the self is an illusory construct – to those that admit its existence – such as James, who, described the spiritual self as something with which we have direct sensible acquaintance and is fully present at any moment of consciousness (James, 1890/1983, p. 286), or Strawson (1997, p. 424), who, without involving any conceptions of agency, personality and long-term diachronic continuity, defines the self as a single, mental thing that is distinct from all other things and is a subject of experience. In this context, I have devised my definition of S by basing it, as much as possible, on current scientific knowledge and empirically ascertained facts, and by following the principle of its functional usefulness in explaining the PAC. As such, S can be considered as an appropriate and comprehensive scientific construct. Obviously, as all constructs, it can be modified, improved or even abandoned in favor of other constructs if the latter prove to work better.

Attention

S can be considered as the main step of the evolutionary process that reduces the complexity inherent to the composite structure of an organism into the "single voice" (Damasio, 2010) of a single entity – a reduction, which, as we have seen, helps the agent to behave in a coordinated manner and avoid conflicting responses. This process was mainly achieved through the activity performed by neurons and the nervous system, which allows for the creation of representational patterns (e.g., topographic maps, transient neural patterns) that are capable of mapping the agent's activity.

The ultimate step of this process of reduction was phylogenetically achieved by attention and its direct product: conscious experience.

Attention is a mechanism[6] (Kahneman, 1973, p. 2) that allows for the realization of a single "perspectival point" from which the agent can experience objects: whatever we perceive, think, etc. is always perceived, thought etc. from a unique perspective, and arrayed around this perspectival. This point makes attentional focusing always directed "toward something" and partitions the world into an asymmetric space that makes us perceive objects from our perspective. This is possible because attention is deployed from a single point inside our body, which, according to Merker (2013a, p. 9), "is located at the proximal-most end of any line of sight or equivalent line of attentional focus."

The reduction process is further strengthened by the periodic nature of attention, which makes it possible to restrict conscious processing to temporally limited and distinct processing epochs (Pöppel, 1997, 2004: Wittmann, 2011). By framing one's conscious experience on a temporal basis, one can reduce and divide the uninterrupted, chaotic and manifold stream of stimuli into basic units, real "building blocks" that can be used (with the support of WM and the other kinds of memory) to form ordered and more complex sequences (Marchetti, 2014).

The periodic (or "pulsing") nature of attention has been empirically verified by a number of experiments that used behavioral, psychophysical or electrophysiological methods. The experiments showed that attention operates rhythmically at a frequency that ranges from 0.5 to 10 Hz approx. (VanRullen et al., 2007; Bush and VanRullen, 2010; Landau and Fries, 2012; Fiebelkorn et al., 2013; VanRullen, 2013, 2018; Song et al., 2014; Zoefel and Sokoliuk, 2014; Dugué et al., 2015; Landau et al., 2015; Fiebelkorn and Kastner, 2019; Senoussi et al., 2019; Zalta et al., 2020).

Finally, attention further enhances the reduction process by allowing the agent to select just one or a very few elements, and suppress the other stimuli. The selection process can variously occur: attention can be deployed exogenously or endogenously (Theeuwes, 1991, 2010; Connor et al., 2004; Carrasco, 2011; Chica et al., 2013; Katsuki and Constantinidis, 2014), internally or externally (Chun et al., 2011), spatially (Posner, 1980; Posner and Cohen, 1984), at variable levels of intensity (La Berge, 1983) and for variable amounts of time (La Berge, 1995), at variable levels of size (narrowly or widely) (Treisman, 2006; Demeyere and Humphreys, 2007;

6 It should be noted that this is not the only definition of attention given by scholars. As Styles (1997) observed, attention is not a unitary concept and there is disagreement as to what its nature is: for example, Anderson (2011) discards the causal conception of attention in favor of an effect account of attention. I adopt the definition of attention as a mechanism because, among the various definitions that are empirically plausible, it is the most functional to the hypothesis I put forward in this article.

Alvarez, 2011; Chong and Evans, 2011), simultaneously between central processes and peripheral processes, as well as between different perceptual modalities (Pashler, 1998).

This has led Tamber-Rosenau and Marois (2016) to conceptualize attention as a structured mechanism arranged in various levels and parts having different functional roles, such as: a central level for abstract, cognitive processes, a mid-level containing priority maps that bias competitions in representational formats and sensory modalities, and a peripheral level for sensory processes.

Working memory

The basic "building blocks" shaped by attention can be combined and assembled by WM, in order to form longer and more complex experiential sequences.

Working memory maintains information in a heightened state of activity in the absence of the corresponding input over a short period, in order to allow for its manipulation during ongoing cognitive processing. This makes it possible for the agent to perform various kinds of operations, from relatively simple ones – such as comparing two items, constructing an item using another item as a model – to more complex ones, such as flexibly combining elements into new structures (Oberauer, 2009), imagining future events (Hill and Emery, 2013) and integrating information from the past into representations of the present or future (Hasson et al., 2015; Parr and Friston, 2017).

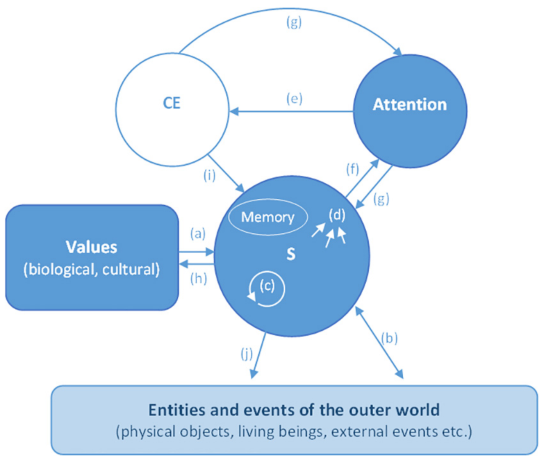

FIGURE 1
Conscious information processing: its main component parts. *S (the self)*: S develops and works on the agent's innate biological and culturally acquired values **(a)**. The interactions between S and the outer world **(b)**, the inner processes of S (e.g., routines automatically triggered by unconscious perception or by conscious experiences) **(c)** and the memory system (long term memory, working memory, procedural memory, etc.) usually induce changes in the state of S **(d)**, which provide the content for attentional processing (but the content can also be represented by the absence of any change). *Attention*: Attentional processing produces **(e)** conscious experience (CE). Attention can be stimulus, bottom–up driven **(f)** or can be voluntarily, top–down directed according to the agent's consciously processed goals **(g)**. *Conscious experience (CE)*: Conscious experience engenders temporary or permanent modifications of S (via the memory system) **(i)**, pilots attention **(g)**, triggers intentional actions **(j)**, unconscious processing **(c)**, and induces modifications of cultural values **(h)**.

Working memory also helps to correctly discriminate relevant from irrelevant information, by preventing the interference of automatic tendencies and routines (Unsworth and Engle, 2007).

Neuroscientific studies have started to elucidate the possible mechanisms underlying WM (Fingelkurts et al., 2010; Lisman and Jensen, 2013; Roux and Uhlhaas, 2014). For example, according to Roux and Uhlhaas (2014), it is the cross-frequency coupling (CFC) between theta, alpha and gamma oscillations that underpins WM activity. Gamma-band oscillations would reflect a generic mechanism for active maintenance of WM information, theta-band oscillations would be involved in the temporal organization of WM items, and oscillatory activity at alpha frequencies would play a critical role in protecting WM items from non-relevant information. CFC between theta- and gamma-band oscillations would "provide a code for representing multiple and sequentially ordered WM items in which cycles of gamma-band oscillations are coordinated through an underlying theta rhythm" (Roux and Uhlhaas, 2014, p. 22). On the contrary, CFC between gamma and alpha oscillations would be involved in the maintenance of sensory-spatial WM items.

Conscious information processing is produced by the interaction between attention and S

Conscious information processing is produced by the interaction between attention and S, when the state of S is focused on by attention. Before such an interaction, there is no consciousness: consciousness only emerges from it[7]. The state of S provides the content of attentional processing and consequently of consciousness. Usually, attention focuses on and enhances the changes of the state of S, and mainly those

7 Philosophers distinguish between strong (or radical) emergence and weak emergence (Searle, 1992; Chalmers, 2006; Searle calls them emergence2 and emergence1, respectively). A strong emergence view claims that consciousness cannot be deduced from the domain from which it arises: that is, the causal interactions between elements of the brain cannot explain the existence of consciousness. Consequently, such a view leads to the idea of an explanatory gap between consciousness and the brain. On the contrary, a weak emergence view claims that consciousness can be explained as the product of brain processes (see Feinberg and Mallatt, 2020, for a convincing argumentation - from a biological and neurobiological perspective – of the plausibility of the weak emergence view). What I am proposing is a weak type of emergence.

that are physically salient, or most relevant for the agent's current goals or selection history (what the agent has learnt in the past: Awh et al., 2012), or for the maintenance of the agent's homeostatic values. However, the content of attentional processing can also be represented by the absence of any change of the state of S (see **Figure 1**).

The changes of the state of S can be generated endogenously, such as when the level of our blood sugar drops or exogenously, such as when an object attracts our attention. They can be directly induced by a voluntary decision, such as when we purposefully think about something, or indirectly triggered as part of a routine action. The kind of change depends on the structures and levels of S that are involved by the change. For example, when we interact with physical objects, changes can occur at the levels of the specialized sensory system involved (touch, smell, etc.), but also of the musculoskeletal system. The changes of the state of S can have various durations, from short intervals of the orders of milliseconds to long intervals of the order of several seconds. Sometimes, these changes can induce automatic reactions intended to reestablish the homeostatic range, but they can also require no specific corrective activity by the agent.

It is important to note that not always what is focused on by attention becomes conscious: actually, there can be attention without conscious experience (Naccache et al., 2002; Montaser-Kousari and Rajimehr, 2004; Sumner et al., 2006; Bahrami et al., 2008).

Some scholars (Lamme, 2003; Koch and Tsuchiya, 2006; van Boxtel et al., 2010; Bachman, 2011) have gone so far as to claim that there can also be consciousness without attention. However, as highlighted by various scholars (Srinivasan, 2008; Kouider et al., 2010; Marchetti, 2012; Pitts et al., 2018; Munévar, 2020; Noah and Mangun, 2020), this claim seems to result from a wrong interpretation of the experimental data, which originated from not having considered the various forms and levels that attention (Nakayama and Mackeben, 1989; La Berge, 1995; Lavie, 1995; Pashler, 1998; Treisman, 2006; Demeyere and Humphreys, 2007; Koivisto et al., 2009; Alvarez, 2011; Chun et al., 2011; Tamber-Rosenau and Marois, 2016; Simione et al., 2019) and consciousness (Tulving, 1985; Edelman, 1989; Iwasaki, 1993; Bartolomeo, 2008; Vandekerckhove and Panksepp, 2009; Northoff, 2013; Northoff and Lamme, 2020) can assume. In fact, not all forms of attention produce the same kind of consciousness, and not all forms of consciousness are produced by the same kind of attention; there can be kinds of conscious experience with no top–down attention but with bottom-up attention; there can be kinds of conscious experience in the absence of a focal form of top–down attention but in the presence of a diffused form of top–down attention. In sum, there can be cases of attention without consciousness, but never cases of consciousness in complete absence of some form of attention: attention is necessary for consciousness.

Complex forms of conscious experiences, such as the various modes of givenness of conscious experience and the stream of consciousness, require the support of the memory system, and notably, of WM. WM allows for the combining and assembling of the basic pieces of information that are isolated and shaped by attention.

Incidentally, it should be noted that for some researchers, the activity of WM can be ultimately traced back to the working of attention: WM functions would emerge when attention, being internally oriented toward the neural systems that were originally involved in the processing of the object/event to be remembered, allows for their recruitment and activation, and consequently for the re-processing of the object/event (Postle, 2006; Lückmann et al., 2014).

What the agent consciously experiences can have various kinds of consequences for the agent: for example, it can lead the agent to voluntarily perform some actions, modify its acquired cultural or social values, or perform further unconscious processes. Importantly, conscious experience usually triggers adaptation and learning processes that lead, via the memory system, to more or less permanent changes of S. Once implemented, these changes alter the way the agent's brain processes information: for example, repeated processing of a stimulus leads to habituation, and repeated practice to automatization of the practiced skill (Baars, 1988). This implies that an agent never experiences the same object twice in the same way because the relationship between it and the object undergoes continuous transformations. One of the most relevant consequences of such changes is the development of reflective self-awareness, which fundamentally enhances the agent's autonomy by allowing it to set its own objectives and directly control its own behavior. Incidentally, it should be noted that there are cases in which conscious processing does not trigger any learning process, such as in the case of amnesic patients (Damasio, 1999), who, despite exhibiting conscious behavior, are unable to learn any new fact.

Phenomenal aspect of consciousness production: Attentional activity and the modulation of the energy level of the organ of attention

What is the process that allows attention to render the state of S conscious, that is, to assign it the phenomenal aspect characteristic of conscious experience (the PAC)? According to my hypothesis (Marchetti, 2010, 2018), (voluntary or involuntary) attentional activity (AA), by focusing on and enhancing the (changes or absence of changes of the) state of S, engenders a modulation of the energy level of the neural substrate that underpins AA itself: *it is precisely this modulation that produces the PAC.*

My hypothesis is based on the assumptions that:

(a) What makes AA possible is the neural energy provided by the neural substrate that constitutes the organ of attention (OA);
(b) The detection of the state of S by means of AA modulates the energy level of the OA.

More specifically, given that attention can be considered a structured mechanism that is arranged in various levels and parts having different functional roles (Tamber-Rosenau and Marois, 2016), the OA can also be considered as structured in various levels and parts, each supporting these different roles. Consequently, the modulation affects only those levels and parts of the OA (from now on, "OA area") that underpin the detection of the state of S.

My assumptions are based on a number of observations and evidence.

The idea that attention is based on an energy pool has a consolidated history. It was first put forward by Kahneman (1973), on the footsteps of David Rapaport. Although initial research seemed to show the existence of a "general-purpose" energy pool, subsequent experiments have shown that there are a variety of resources that are "task specific" (McLeod, 1977; Duncan, 1984; Pashler, 1989). Various psychological experiments and observations clearly show that such a pool is limited: the possibility of sharing attention is limited by the task demands: when one task demands more resources, there will be less capacity left over for the other tasks (Lavie, 1995); there is a limit to increasing mental processing capacity by increasing mental effort and arousal; an extensive use of attention, as demanded by complex, time-consuming tasks, requires some time to recover the consumed energy; etc.

The concept of an "organ of attention" is not new: many scientists have already started investigating the neural and brain structures constituting it (Mesulam, 1990; Posner and Petersen, 1990; Crick, 1994; Crick and Koch, 2003). However, the search for such an organ is not fully uncontroversial. As De Brigard (2012) highlights, there is disagreement as to the nature of the neural correlate of attention: some scholars suggest that there may not be a single neural process responsible for all forms of attention (Wu, 2011), while some others see attention as a unified cognitive process with an identifiable sub-personal neural correlate (Prinz, 2011). Undoubtedly, only a clear definition of the features and roles of attention can help define the nature of its organ.

The concept of neural energy has been prevalently studied with regard to its consumption (in terms of demand of adenosine triphosphate, ATP) during neural informational processes, that is, for its support function in information processing (Laughlin et al., 1998; Laughlin, 2001; Laughlin and Attwell, 2004; Shulman et al., 2009; Sengupta et al., 2010). Recent studies have started investigating how to decode the information of stimulus and neural response from the energy metabolism (Wang et al., 2017). However, to my knowledge, no empirical work has been conducted so far to investigate neural energy in connection with AA as I have theorized it.

The concept of energy has been explicitly associated with consciousness in recent studies (Street, 2016; Pepperell, 2018). However, these studies tackle preferentially the how of the PAC – how it is brought about – rather than the why of the PAC: Street highlights that consciousness and its major features derive from an efficient use of energy and the maximization of thermodynamic efficiency ("self-awareness may be a mechanism for optimizing the brain's consumption of energy") and Pepperel focuses on how conscious experience is brought about by a certain organization of the energetic activity in the brain (conscious experience is caused by "a certain dynamic organization of energetic processes having a high degree of differentiation and integration").

The idea that AA engenders a modulation of the energy level of the OA primarily derives from the observation of the extreme consequences that such a modulation can bring about, such as when the normal flow of attention is dramatically slowed down or even interrupted. This is the case of pain. A nociceptive signal captures attention. This engenders a modulation of the energy level of the OA that, in the case of acute or persistent pain, can lead to an interruption of the normal flow of attention (so much so that, in order to reestablish the normal state, we must either divert our attention toward something else or try to remove the cause of the pain) (Eccleston and Crombez, 1999; Haikonen, 2003; Legrain et al., 2009) – which is precisely what the experience of pain consists in.

It is important to highlight that the working of the OA, like the working of any other organ of the organism, depends on the energy supplied by the organism. To work properly, the OA needs a certain amount of energy. The amount of energy needed by the OA can vary according to various factors, such as the agent's expectations and motivations, and the task that the agent has to perform. It is my hypothesis that the amount of energy that the organism supplies to the OA determines the agent's state of arousal (or wakefulness). Various states of arousal are possible (some of which can also be induced pharmacologically): conscious wakefulness, REM sleep, deep sleep, vegetative state, near-death experience (NDE), coma, etc. (Laureys, 2005; Laureys et al., 2009). One of these states – NDE – is particularly interesting, because it apparently represents a challenge to physicalists theories of mind and consciousness. Greyson (2000, pp. 315–316) defines NDEs as "profound psychological events with transcendental and mystical elements, typically occurring to individuals close to death or in situations of intense physical or emotional danger." Prototypical features of NDE are out-of-body experiences (OBE), experiencing a panoramic life review, feeling of peace and quiet, seeing a dark tunnel, experiencing a bright light (Vanhaudenhuyse et al., 2009; Martial et al., 2020). While some scholars believe that it is possible to explain NDEs in psychological or neurobiological terms (see for example Mobbs and Watt, 2011; Martial et al., 2020), some other scholars argue that physicalists theories of the mind cannot explain how people can experience the vivid and complex thoughts of the NDE, given that brain activity is seemingly absent (see for example Haesler and Beauregard, 2013; van Lommel, 2013). I think that the theoretical framework proposed by Martial et al. (2020), which is compatible with my model of consciousness, and their analysis of NDE, can help to define how the brain generates NDE without postulating any paranormal cause. According to Martial et al. (2020), consciousness has three main components – wakefulness, connectedness (akin to external awareness) and internal awareness –, which allow for mapping the various states of consciousness. In a normal conscious awake state, the three components are at their maximum level, while states such as coma and general anesthesia have these three components at their minimum level. NDE corresponds to internal awareness with a disconnection from the environment experienced in unresponsive conditions. In terms of my model, this means that attention is deployed only internally and that the amount of energy that the organism supplies to the OA is almost negligeable, albeit sufficient for OA to support some (minimal) kind of AA.

The main dimensions of the phenomenal aspect of consciousness and their relation to the modulation of the energy level of the organ of attention area

As I said, according to my hypothesis, the PAC is brought about by the modulation of the energy level of the OA area that is consequent upon the (voluntary or involuntary) use of attention. The PAC can be qualified according to at least five main dimensions: qualitative, quantitative, hedonic, temporal and spatial (see also Cabanac, 2002, who however does not include the spatial dimension). Each dimension can be traced back to a specific feature of the modulation of the energy level of the OA area (see **Table 1**).

The qualitative dimension of the PAC is defined by the OA area that, underpinning the attentional processing of the state of S, is modulated by such an attentional processing. This means that what an agent consciously experiences about the state of S also depends on the way the agent attentionally processes the state of S (and consequently on the areas of the OA involved), rather than on the state of S alone. In fact, the same state of S may undergo different levels of attentional processing, which lead to different conscious experiences of the state itself (affective, cognitive, sensory, etc.)[8].

The quantitative dimension is defined by the amount of variation of the energy level of the OA area caused by the modulation.

The hedonic dimension (e.g., pleasant vs. unpleasant) is defined by the direction of the variation of the energy level of the OA area relative to the set-point at which the level of the area is regulated[9]. Pleasant and unpleasant experiences occur when the energy level moves toward or away from the set-point, respectively. More precisely, painful experiences take place when the energy level moves away from the set-point beyond a certain threshold. When this occurs, the agent's flow of attention is diverted from any ongoing task and is fully absorbed by the painful stimulus and its possible causes, so that the agent can take the necessary actions to restore the original energy level of the OA area. Pleasant experiences occur when the energy level of the OA area is restored to its original value after it was brought beyond a certain threshold. Neutral experiences – or "comfort" as defined by Cabanac (2013), a state characterized by physiological normality and indifference toward the environment -, occur when the energy level fluctuates within an acceptable range of the set-point.

Incidentally, it is interesting to note that Solms (2019) has proposed a similar mechanism for affect (the technical term for feeling). Solms identifies affect as the elemental form of consciousness, which has its physiological mechanism (an extended form of homeostasis) in the upper brainstem. Affect enables complex organisms to register, regulate and prioritize deviations from homeostatic settling points in unpredicted contexts. Deviations away from a homeostatic settling point is felt as unpleasure, and returning toward it is felt as pleasure. Solms' proposal very much resembles my proposal in that it explains the hedonic dimension in terms of deviations to and from a set-point (but this is not the only point of resemblance: it also stresses the importance of investigating the function of conscious experience to overcome the explanatory gap, and poses a fundamental biological imperative – to minimize expected free energy – at the basis of the existence and survival of self-organizing systems). However, his proposal substantially differs from mine because it explains affects in purely homeostatic terms rather than in attentional ones (as deviations to and from the set-point at which the level of the OA area is regulated). In my view, Solms' proposal precludes the possibility of explaining how the various kinds of variations of the self (chemical, electrical, mechanical, etc.) can be translated into the "common language" of consciousness: a translation that

8 See also Northoff and Lamme (2020, p. 579), who, even if they adopt a different model of consciousness, recognize that: the "very same contents may undergo different levels of processing and different functions like sensory, cognitive, affective, which modulates these contents allowing us to access them in different ways."

9 Set-points, even if innately determined, can – up to a certain limit - be adjusted by the agent according to its plans, goals, motivation, etc. Consequently, a stimulus such as a non-painful thermal one can be perceived either as pleasant or unpleasant according to the internal thermal state of the agent (Cabanac, 1971, 2006).

TABLE 1 PAC dimensions, how they relate to the modulation of the energy level of the OA area, and the features of the sense of self involved.

PAC dimension	Features of the modulation of the energy level of the OA area that define the PAC dimension	Features of the sense of self involved
Qualitative	OA area involved by the modulation	Single voice
Quantitative	Amount of variation of the energy level	Single voice
Hedonic	Direction of variation of the energy level relative to the set-point at which the level of the OA area is regulated	Boundaries of the self and sense of mineness
Temporal	Periodicity of the modulation of the energy level	Feelings of continuity; single voice
Spatial	Path followed by the modulation of the OA	Point of view; single voice

is made by attention and that makes it possible to compare and differentiate the various dimensions of life. Most probably, this limit of Solms' proposal derives from his overestimation of the role of brainstem as the primary mechanism of consciousness, and underestimation of the role played by other mechanisms (this has also been observed by Safron, 2021).

The information provided by how the energy level of the OA area varies relative to the set-point at which the level of the area is regulated is fundamental for building the sense of mineness (or ownership) and defining the boundary between self and non-self. Considering for example the set-points related to homeostatic regulation, a departure of the energy level from the set-point indicates a departure from what is under the control of the agent. Some other mechanisms were proposed to account for the sense of mineness and the distinction between self and world, such as the comparator model (Gallagher, 2000; Legrand, 2006). However, as pointed out by Vosgerau and Newen (2007), these models presuppose the self-world distinction rather than explaining it. Actually, the agent, in order to learn the effects of its own movement, must already know which of its movements is caused by itself and which is not (for further criticisms of the comparator model, see Synofzik et al., 2008): a knowledge that, in my view, can only be provided by the hedonic dimension.

The temporal and spatial dimensions of the PAC are determined by the manner in which attention works. The temporal dimension of the PAC is determined by the periodic nature of attention. As we have seen, attention works in a periodic manner. On the one hand, this limits the duration of the modulation of the energy level of the OA and consequently of any conscious experience. On the other hand, it represents the necessary condition for the activity of modulation to be repeatedly performed, and consequently to produce – with the support of WM – the feeling that our experience flows uninterruptedly.

The spatial dimension of the PAC is determined by the egocentric spatial nature of attention. Every attentional pulse originates and is deployed from a single point located inside our body, and is directed toward something. Consequently, whatever is focused by attention, appears in our consciousness as possessing a spatial quality that is defined through the center of attention and the direction toward which attention is focused. The path that attention takes at every new cycle of its activity is reflected in the OA area that underpins and is modulated by the activity performed by attention. The modulation of the OA follows the path taken by attention: it starts from the point where attention originates and continues to the point where the deployment of attention stops.

A clarification is in order concerning the temporal and spatial dimensions. These features of the PAC must not be confused with the conscious experience of time and space, respectively. One thing is the experiences of time and space, quite another the temporal and spatial dimensions of experience. You can consciously experience something (e.g., an emotion) without experiencing or being aware of the temporal or spatial dimension of your experience. The temporal and spatial dimension of the PAC are a precondition for any experience to occur[10], including the experiences of time and space, but they are not in themselves experiences of time and space. For such experiences to occur, a specific assembling – performed with the support of WM – of the contents selected by attention is necessary (Marchetti, 2014)[11].

10 See for example Koivisto et al.'s (2009) experiments, which clearly show that spatial attention is a prerequisite for any conscious experience to occur, and Donovan et al. (2017), who show that spatial attention is necessary for object-based attention.

11 According to my hypothesis (Marchetti, 2009, 2014), this same construction principle, which involves attention and WM, has allowed human beings to build – starting from the basic, psychological experiences of time and space – more abstract concepts of time and space, such as the time and space of physics. In this view, the time and space of physics are derivative on the psychological experiences of time and space. This is evidenced by the fact that everything we know is known primarily in and through our conscious experiences: only successively can we "abstract" or rationalize our experience, and develop those *entia rationis* that characterize physics as well as the other sciences. As Vicario (2005, p. 13) observes : "The vocabulary of physics

A final consideration concerning the evolutionary origins of consciousness: did all the five dimensions of the PAC appear together at the same time, or did one or some of them appear before the others? If we adopt the evolutionary transition marker adopted by Bronfman et al. (2016) (unlimited associative learning) or the neurobiological features of consciousness listed by Feinberg and Mallatt (2013) and Feinberg and Mallatt (2019) as criteria to define the appearance of consciousness, it seems quite reasonable to conclude that all the five dimensions of the PAC emerged phylogenetically together at the same time (obviously, because of the different sensory and brain machinery with which different species are endowed, the five dimensions can differ between the various species: for example, what a fly sees, is qualitatively different from what we humans see Lamme, 2018). However, stricter criteria can lead to different conclusions.

Conclusion

In this article, I have put forward an explanation of the difference that the PAC makes for information processing and for the agent processing it. My view is that the PAC supplies the agent with a sense of self, and informs the agent on how its self is affected by its own operations. This has many advantages for the agent, among which the most relevant are that the agent can: see itself as an entity among, and differentiated from, other entities; build a knowledge of how other entities and events refer to itself; build a knowledge about itself and ultimately develop a form of reflective self-awareness; produce coordinated behaviors and avoid conflicting actions that could damage its integrity. In turn, this allows the agent to (at least up to a certain point) set its own goals and avoid automatic responses, act independently from the influence of its natural and social environment, build an autonomous knowledge by resisting possible wrong information, and on that basis, form justified, supported beliefs: in a word, to dramatically enhance the agent's autonomy (Castelfranchi, 2012).

The PAC performs its two main functions (providing the agent with a sense of self, and informing the agent about how the agent's self is affected by the agent's own operations) through its five main dimensions: qualitative, quantitative, hedonic, temporal, and spatial.

As to the sense of self, we have seen that it provides the agent with the feeling of being an entity differentiated from other entities, the presence of a "point of view," the capacity to represent itself with a "single voice" and the feeling of continuity. Each of these features is shaped through the five dimensions of the PAC (see **Table 1**). The hedonic dimension, by signaling how much the energy level of the OA deviates from the set-point, contributes to defining the boundaries of the agent and the sense of mineness; the spatial dimension provides the point of view; the qualitative and quantitative dimensions, associated with the limited temporal duration of any conscious experience and the point of view, make the "single voice" possible; the temporal dimension provides the feeling of continuity.

As for the information concerning how the agent's self is affected by the agent's own operations, we have seen that it is made possible by the modulation of the energy level of the OA area that is caused by AA. This modulation affects, both directly and temporarily, the agent's self along some or all of the five dimensions of the PAC. Usually, the most affected dimensions are the qualitative, quantitative and hedonic ones, even though sometimes the spatial and temporal dimensions can be affected as well: for example, novel events seem to last longer the first time they are experienced than the subsequent times, while when witnessing unexpected, dangerous or shocking events, we are induced to perceive time as slowing down, etc.

Even though part of the hypothesis I have put forward in this article is based on empirical evidence, much remains to be experimentally verified: principally, the causal relation between the variations of the energy level of the OA area and the PAC. This preliminarily requires the exact identification and delimitation of the OA and of its various parts, and the possibility to measure its energy level. Moreover, even though it seems intuitive that, in the operative closure of an organism, AA may engender a variation in the energy level of the OA, the existence of such a direct relationship needs to be fully ascertained.

An empirical verification of the hypothesis can also be obtained by using it to build an artificial conscious machine. Among other things, this would allow for accepting or rejecting the opposite claim that a machine (e.g., a robot) that is equipped with S and attention and that displays the five dimensions of PAC, cannot have any conscious experience. To this end, in my view what counts most is that the concepts (and the relations among them) used to describe the hypothesis, can be operationalized, and that they allow one to analyze consciousness in terms of functions that are performed by the working of physical organs.

Finally, my hypothesis is partly compatible with those scientific approaches that conceive consciousness as the result of the nested and synchronized oscillatory neural activity across different time scales, such as Operational Architectonics (Fingelkurts et al., 2010) and Temporo-spatial Theory of Consciousness (Northoff and Huang, 2017). Even though these approaches do not directly address the why of the PAC and do not consider attention as the primary mechanism for consciousness, they account – as my proposal does – for the periodic and transitory nature of conscious processing, for the combinatorial capacity of the brain and for how

derives from everyday language, which describes direct experience, that is, psychological experience."

conscious contents and forms are determined by the state of ongoing oscillatory neural activity.

Data availability statement

The original contributions presented in this study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Adami, C. (2015). Information-theoretic considerations concerning the origin of life. *Orig. Life Evol. Biosph.* 45, 309–317. doi: 10.1007/s11084-015-9439-0

Aleksander, I., and Gamez, D. (2011). "Informational theories of consciousness: a review and extension," in *From Brains to Systems: Brain-Inspired Cognitive Systems 2010*, eds C. Hernández, R. Sanz, J. Gomez, L. S. Smith, A. Hussain, A. Chella, et al. (Berlin: Springer), 139–147. doi: 10.1007/978-1-4614-0164-3_12

Alvarez, G. A. (2011). Representing multiple objects as an ensemble enhances visual cognition. *Trends Cogn. Sci.* 15, 122–131. doi: 10.1016/j.tics.2011.01.003

Anderson, B. (2011). There is no such thing as attention. *Front. Psychol.* 2:246. doi: 10.3389/fpsyg.2011.00246

Awh, E., Belopolsky, A. V., and Theeuwes, J. (2012). Top-down versus bottom-up attentional control: a failed theoretical dichotomy. *Trends Cogn. Sci.* 16, 437–443. doi: 10.1016/j.tics.2012.06.010

Baars, B. J. (1988). *A Cognitive Theory of Consciousness*. Cambridge: Cambridge University Press.

Bachman, T. (2011). Attention as a process of selection, perception as a process of representation, and phenomenal experience as the resulting process of perception being modulated by a dedicated consciousness mechanism. *Front. Psychol.* 2:387. doi: 10.3389/fpsyg.2011.00387

Bahrami, B., Carmel, D., Walsh, V., Rees, G., and Lavie, N. (2008). Unconscious orientation processing depends on perceptual load. *J. Vis.* 8, 1–10. doi: 10.1167/8.3.12

Baluška, F., and Levin, M. (2016). On having no head: cognition throughout biological systems. *Front. Psychol.* 7:902. doi: 10.3389/fpsyg.2016.00902

Bartolomeo, P. (2008). *Varieties of Attention and of Consciousness: Evidence from Neuropsychology Psyche* 14. Available online at: http://journalpsyche.org/archive/volume-14-2008/

Bateson, G. (1972). *Steps to an Ecology of Mind*. Toronto: Chandler.

Bronfman, Z. Z., Ginsburg, S., and Jablonka, E. (2016). The transition to minimal consciousness through the evolution of associative learning. *Front. Psychol.* 7:1954. doi: 10.3389/fpsyg.2016.01954

Bush, N. A., and VanRullen, R. (2010). Spontaneous EEG oscillations reveal periodic sampling of visual attention. *Proc. Natl. Acad. Sci. U.S.A.* 107, 16048–16053. doi: 10.1073/pnas.1004801107

Cabanac, M. (1971). Physiological role of pleasure: a stimulus can feel pleasant or unpleasant depending upon its usefulness as determined by internal signals. *Science* 173, 1103–1107. doi: 10.1126/science.173.4002.1103

Cabanac, M. (2002). What is emotion? *Behav. Processes* 60, 69–83. doi: 10.1016/S0376-6357(02)00078-5

Cabanac, M. (2006). Adjustable set point: to honor Harold T. Hammel. *J. Appl. Physiol.* 100, 1338–1346. doi: 10.1152/japplphysiol.01021.2005

Cabanac, M. (2013). "Sensory pleasure and homeostasis," in *Beyond Environmental Comfort*, ed. B. L. Ong (London: Routledge), 17–35.

Campbell, J. (2011). "Visual attention and the epistemic role of consciousness," in *Attention, Philosophical and Psychological Essays*, eds C. Mole, D. Smithies, and W. Wu (Oxford: Oxford University Press), 323–342.

Carrasco, M. (2011). Visual attention: the past 25 years. *Vision Res.* 51, 1484–1525. doi: 10.1016/j.visres.2011.04.012

Castelfranchi, C. (2012). Autonomy for AGI. *J. Artif. Gen. Intell.* 3, 31–33.

Cerullo, M. A. (2015). The problem with Phi: a critique of integrated information theory. *PLoS Comput. Biol.* 11:e1004286. doi: 10.1371/journal.pcbi.1004286

Chalmers, D. J. (1995). Facing up to the problem of consciousness. *J. Conscious. Stud.* 2, 200–219.

Chalmers, D. J. (1996). *The Conscious Mind: In search of a Fundamental Theory*. Oxford: Oxford University Press.

Chalmers, D. J. (2006). "Strong and weak emergence," in *The Re-Emergence of Emergence: The Emergentist Hypothesis from Science to Religion*, eds P. Clayton and P. Davies (Oxford: Oxford University Press), 244–254. doi: 10.1093/acprof:oso/9780199544318.003.0011

Chica, A. B., Bartolomeo, P., and Lupiáñez, J. (2013). Two cognitive and neural systems for endogenous and exogenous spatial attention. *Behav. Brain Res.* 237, 107–123. doi: 10.1016/j.bbr.2012.09.027

Chong, S. C., and Evans, K. K. (2011). Distributed versus focused attention (count vs estimate). *Wiley Interdiscip. Rev. Cogn. Sci.* 2, 634–638. doi: 10.1002/wcs.136

Chun, M. M., Golomb, J. D., and Turk-Browne, N. B. (2011). A taxonomy of external and internal attention. *Annu. rev. Psychol.* 62, 73–101. doi: 10.1146/annurev.psych.093008.100427

Ciaunica, A., Safron, A., and Delafield-Butt, J. (2021). Back to square one: the bodily roots of conscious experiences in early life. *Neurosci. Conscious.* 2021:niab037. doi: 10.31234/osf.io/zspm2

Cleeremans, A. (2008). Consciousness: the radical plasticity thesis. *Prog Brain Res* 168, 19–33. doi: 10.1016/S0079-6123(07)68003-0

Connor, C. E., Egeth, H. E., and Yantis, S. (2004). Visual attention: bottom-up versus top-down. *Curr. Biol.* 14, R850–R852. doi: 10.1016/j.cub.2004.09.041

Crick, F. (1994). *The Astonishing Hypothesis*. New York, NY: Simon and Schuster.

Crick, F., and Koch, C. (2003). A framework for consciousness. *Nat. Neurosci.* 6, 119–126. doi: 10.1038/nn0203-119

Damasio, A. R. (1998). Investigating the biology of consciousness. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 353, 1879–1882. doi: 10.1098/rstb.1998.0339

Damasio, A. R. (1999). *The Feeling Of What Happens: Body, Emotion and the Making of Consciousness*. New York, NY: Random House.

Damasio, A. R. (2010). *Self Comes To Mind: Constructing the Conscious Brain*. New York, NY: Random House.

De Brigard, F. (2012). The role of attention in conscious recollection. *Front. Psychol.* 3:29. doi: 10.3389/fpsyg.2012.00029

Dehaene, S., and Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. *Cognition* 79, 1–37. doi: 10.1016/S0010-0277(00)00123-2

Demeyere, N., and Humphreys, G. (2007). Distributed and focused attention: neuropsychological evidence for separate attentional mechanisms when counting and estimating. *J. Exp. Psychol. Hum Percept. Perform.* 33, 1076–1088. doi: 10.1037/0096-1523.33.5.1076

Dennett, D. C. (1991). *Consciousness Explained*. New York, NY: Little, Brown and Company.

Di Francesco, M. (2000). *La coscienza*. Bari: Laterza.

Di Francesco, M., and Marraffa, M. (2013). The unconscious, consciousness, and the Self illusion. *Dial. Phil. Ment. Neuro Sci.* 6, 10–22.

Di Paolo, E., Thompson, E., and Beer, R. (2022). Laying down a forking path: tensions between enaction and the free energy principle. *Philoso. Mind Sci.* 3, 1–39. doi: 10.33735/phimisci.2022.9187

Donovan, I., Pratt, J., and Shomstein, S. (2017). Spatial attention is necessary for object-based attention: evidence from temporal-order judgments. *Atten. Percept. Psychophys.* 79, 753–764. doi: 10.3758/s13414-016-1265-6

Dretske, F. (1981). *Knowledge and the Flow of Information*. Oxford: Blackwell.

Dugué, L., McLelland, D., Lajous, M., and VanRullen, R. (2015). Attention searches nonuniformly in space and in time. *Proc. Natl. Acad. Sci.* 112, 15214–15219. doi: 10.1073/pnas.1511331112

Duncan, J. (1984). Selective attention and the organization of visual information. *J. Exp. Psychol. Gen.* 113, 501–517. doi: 10.1037/0096-3445.113.4.501

Earl, B. (2014). The biological function of consciousness. *Front. Psychol.* 5:697. doi: 10.3389/fpsyg.2014.00697

Eccleston, C., and Crombez, G. (1999). Pain demands attention: a cognitive–affective model of the interruptive function of pain. *Psychol. Bull.* 125:356. doi: 10.1037/0033-2909.125.3.356

Edelman, G. M. (1989). *The Remembered Present: A Biological Theory of Consciousness*. New York, NY: Basic Books.

Evans, C. O. (1970). *The Subject of Consciousness*. London: George Allen & Unwin Ltd.

Facco, E., Al Khafaji, B. E., and Tressoldi, P. (2019). In search of the true self. *J. Theor. Philos. Psychol.* 39:157. doi: 10.1037/teo0000112

Farnsworth, K. D., Nelson, J., and Gershenson, C. (2013). Living is information processing: from molecules to global systems. *Acta Biotheor.* 61, 203–222. doi: 10.1007/s10441-013-9179-3

Feinberg, T. E., and Mallatt, J. (2019). Subjectivity "demystified": neurobiology, evolution, and the explanatory gap. *Front. Psychol.* 10:1686. doi: 10.3389/fpsyg.2019.01686

Feinberg, T. E., and Mallatt, J. (2020). Phenomenal consciousness and emergence: eliminating the explanatory gap. *Front. Psychol.* 11:1041. doi: 10.3389/fpsyg.2020.01041

Feinberg, T. E., and Mallatt, J. (2013). The evolutionary and genetic origins of consciousness in the Cambrian Period over 500 million years ago. *Front. Psychol.* 4:667. doi: 10.3389/fpsyg.2013.00667

Fiebelkorn, I. C., and Kastner, S. (2019). A rhythmic theory of attention. *Trends Cogn. Sci.* 23, 87–101. doi: 10.1016/j.tics.2018.11.009

Fiebelkorn, I. C., Saalmann, Y. B., and Kastner, S. (2013). Rhythmic sampling within and between objects despite sustained attention at a cued location. *Curr. Biol.* 23, 2553–2558. doi: 10.1016/j.cub.2013.10.063

Fingelkurts, A. A., and Fingelkurts, A. A. (2017). Information flow in the brain: ordered sequences of metastable states. *Information* 8:22. doi: 10.3390/info8010022

Fingelkurts, A. A., Fingelkurts, A. A., and Neves, C. F. H. (2010). Natural world physical, brain operational, and mind phenomenal space-time. *Phys. Life Rev.* 7, 195–249. doi: 10.1016/j.plrev.2010.04.001

Fingelkurts, A. A., Fingelkurts, A. A., and Neves, C. F. H. (2013). Consciousness as a phenomenon in the operational architectonics of brain organization: criticality and self-organization considerations. *Chaos Solitons Fract.* 55, 13–31. doi: 10.1016/j.chaos.2013.02.007

Floridi, L. (2005). Is semantic information meaningful data? *Philoso. Phenomenol. Res.* 70, 351–370. doi: 10.1111/j.1933-1592.2005.tb00531.x

Frigato, G. (2021). The neural correlates of access consciousness and phenomenal consciousness seem to coincide and would correspond to a memory center, an activation center and eight parallel convergence centers. *Front. Psychol.* 12:749610. doi: 10.3389/fpsyg.2021.749610

Friston, K. J., FitzGerald, T., Rigoli, F., Schwartenbeck, P., and Pezzulo, G. (2017). Active inference: a process theory. *Neural Comput.* 29, 1–49. doi: 10.1162/NECO_a_00912

Friston, K. J., Kilner, J., and Harrison, L. (2006). A free energy principle for the brain. *J. Physiol. Paris* 100, 70–87. doi: 10.1016/j.jphysparis.2006.10.001

Frith, C. (2010). What is consciousness for? *Pragmat. Cogn.* 18, 497–551. doi: 10.1075/pc.18.3.03fri

Gallagher, S. (2000). Philosophical conceptions of the self: implications for cognitive science. *Trends Cogn. Sci.* 4, 14–21. doi: 10.1016/S1364-6613(99)01417-5

Gallagher, S. (2017). Self-defense: deflecting deflationary and eliminativist critiques of the sense of ownership. *Front. Psychol.* 8:1612. doi: 10.3389/fpsyg.2017.01612

Gallagher, S., and Zahavi, D. (2008). *The Phenomenological Mind. An Introduction To Philosophy Of Mind and Cognitive Science*. London: Routledge. doi: 10.4324/9780203086599

Greyson, B. (2000). "Near-death experiences," in *Varieties of Anomalous Experiences: Examining the Scientific Evidence*, eds E. Cardena, S. J. Lynn, and S. Krippner (Washington, DC: American Psychological Association), 315–352. doi: 10.1037/10371-010

Haesler, T. V., and Beauregard, M. (2013). Near-death experiences in cardiac arrest: implications for the concept of non-local mind. *Arch. Clin. Psychiatry* 40, 197–202. doi: 10.1590/S0101-60832013000500005

Haikonen, P. O. (2003). *The Cognitive Approach to Conscious Machine*. Exeter: Imprint Academic.

Hasson, U., Chen, J., and Honey, C. J. (2015). Hierarchical process memory: memory as an integral component of information processing. *Trends Cogn. Sci.* 19, 304–313. doi: 10.1016/j.tics.2015.04.006

Hill, P. F., and Emery, L. J. (2013). Episodic future thought: contributions from working memory. *Conscious. Cogn.* 22, 677–683. doi: 10.1016/j.concog.2013.04.002

Hofkirchner, W. (2011). "Does computing embrace self-organisation?," in *Information and Computation*, eds M. Burgin and G. Dodig-Crnkovic (New Jersey, NJ: World Scientific), 185–202. doi: 10.1142/9789814295482_0007

Hofkirchner, W. (2013). Emergent information. When a difference makes a difference. *TripleC* 11, 6–12. doi: 10.31269/triplec.v11i1.330

Hofkirchner, W. (2014). "Epistemology and the Study of Social Information within the Perspective of a Unified Theory of Information," in *Theories of Information, Communication and Knowledge. A Multidisciplinary Approach*, eds F. Ibekwe-SanJuan and T. M. Dousa (Dordrecht: Springer), 51–69. doi: 10.1007/978-94-007-6973-1_3

Hume, D. (1739/1985). *A Treatise of Human Nature*. London: Penguin Classics. doi: 10.1093/oseo/instance.00046221

Husserl, E. (1989). "Ideas pertaining to a pure phenomenology and to a phenomenological philosophy," in *Book 2: Studies in the Phenomenology of Constitution*, Vol. 3, eds R. Rojcewicz and A. Schuwer (Dordrech: Kluwer). doi: 10.1007/978-94-009-2233-4

Iwasaki, S. (1993). Spatial attention and two modes of visual consciousness. *Cognition* 49, 211–233. doi: 10.1016/0010-0277(93)90005-G

James, W. (1890/1983). *The Principles of Psychology*. Cambridge: Harvard University Press.

Jonkisz, J. (2015). Consciousness: individuated information in action. *Front. Psychol.* 6:1035. doi: 10.3389/fpsyg.2015.01035

Jonkisz, J. (2016). Subjectivity: a case of biological individuation and an adaptive response to informational overflow. *Front. Psychol.* 7:1206. doi: 10.3389/fpsyg.2016.01206

Josipovic, Z., and Miskovic, V. (2020). Nondual awareness and minimal phenomenal experience. *Front. Psychol.* 11:2087. doi: 10.3389/fpsyg.2020.02087

Kahneman, D. (1973). *Attention and EFfort*. Englewood Cliffs, NJ: Prentice-Hall.

Kanai, R., Chang, A., Yu, Y., Magrans, de Abril, I., Biehl, M., et al. (2019). Information generation as a functional basis of consciousness. *Neurosci. Conscious.* 2019:niz016. doi: 10.1093/nc/niz016

Katsuki, F., and Constantinidis, C. (2014). Bottom-up and top-down attention: different processes and overlapping neural systems. *Neuroscientist* 20, 509–521. doi: 10.1177/1073858413514136

Keller, A. (2014). The evolutionary function of conscious information processing is revealed by its task-dependency in the olfactory system. *Front. Psychol.* 5:62. doi: 10.3389/fpsyg.2014.00062

Koch, C., and Tsuchiya, N. (2006). Attention and consciousness: two distinct brain processes. *Trends Cogn. Sci.* 11, 16–22. doi: 10.1016/j.tics.2006.10.012

Koivisto, M., Kainulainen, P., and Revonsuo, A. (2009). The relationship between awareness and attention: evidence from ERP responses. *Neuropsychologia* 47, 2891–2899. doi: 10.1016/j.neuropsychologia.2009.06.016

Kouider, S., de Gardelle, V., Sackur, J., and Dupoux, E. (2010). How rich is consciousness? The partial awareness hypothesis. *Trends Cogn. Sci.* 14, 301–307. doi: 10.1016/j.tics.2010.04.006

La Berge, D. (1983). The spatial extent of attention to letters and words. *J. Exp. Psychol. Hum. Percept. Perform.* 9, 371–379. doi: 10.1037/0096-1523.9.3.371

La Berge, D. (1995). *Attentional Processing. The Brain's Art of Mindfulness*. Cambridge, MA: Harvard University Press. doi: 10.4159/harvard.9780674183940

Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends Cogn. Sci.* 7, 12–18. doi: 10.1016/S1364-6613(02)00013-X

Lamme, V. A. F. (2018). Challenges for theories of consciousness: seeing or knowing, the missing ingredient and how to deal with panpsychism. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 373:20170344. doi: 10.1098/rstb.2017.0344

Landau, A. N., and Fries, P. (2012). Attention samples stimuli rhythmically. *Curr. Biol.* 22, 1000–1004. doi: 10.1016/j.cub.2012.03.054

Landau, A. N., Schreyer, H. M., Van Pelt, S., and Fries, P. (2015). Distributed attention is implemented through theta-rhythmic gamma modulation. *Curr. Biol.* 25, 2332–2337. doi: 10.1016/j.cub.2015.07.048

Laughlin, S. B. (2001). Energy as a constraint on the coding and processing of sensory information. *Curr. Opin. Neurobiol.* 11, 475–480. doi: 10.1016/S0959-4388(00)00237-3

Laughlin, S. B., and Attwell, D. (2004). "Neural energy consumption and the representation of mental events," in *Brain Energetics and Neuronal Activity*, eds R. G. Shulman and D. L. Rothman (Chichester: John Wiley and Sons), 111–124. doi: 10.1002/0470020520.ch7

Laughlin, S. B., de Ruyter, van Steveninck, R. R., and Anderson, J. C. (1998). The metabolic cost of neural information. *Nat. Neurosci.* 1, 36–41. doi: 10.1038/236

Laureys, S. (2005). The neural correlate of (un) awareness: lessons from the vegetative state. *Trends Cogn. Sci.* 9, 556–559. doi: 10.1016/j.tics.2005.10.010

Laureys, S., Boly, M., Moonen, G., and Maquet, P. (2009). "Coma," in *Encyclopedia of Neuroscience*, ed. L. R. Squire (London: Elsevier), 2. doi: 10.1016/B978-008045046-9.01770-8

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *J. Exp. Psychol. Hum. Percept. Perform.* 21, 451–468. doi: 10.1037/0096-1523.21.3.451

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., and Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain* 144, 230–232. doi: 10.1016/j.pain.2009.03.020

Legrand, D. (2006). The bodily self: the sensori-motor roots of prereflective self-consciousness. *Phenomenol. Cogn. Sci.* 5, 89–118. doi: 10.1007/s11097-005-9015-6

Legrand, D. (2007). Pre-reflective self-consciousness: on being bodily in the world. *Janus Head* 9, 493–519. doi: 10.5840/jh20069214

Lisman, J. E., and Jensen, O. (2013). The theta-gamma neural code. *Neuron* 77, 1002–1016. doi: 10.1016/j.neuron.2013.03.007

Lückmann, H. C., Jacobs, H. I., and Sack, A. T. (2014). The cross-functional role of frontoparietal regions in cognition: internal attention as the overarching mechanism. *Prog. Neurobiol.* 116, 66–86. doi: 10.1016/j.pneurobio.2014.02.002

Mangan, B. (2001). Sensation's ghost. The non-sensory "fringe" of consciousness. *Psyche* 7, 1–44.

Marchetti, G. (2009). Studies on time: a proposal on how to get out of circularity. *Cogn. Process.* 10, 7–40. doi: 10.1007/s10339-008-0215-1

Marchetti, G. (2010). *Consciousness, Attention and Meaning*. New York, NY: Nova Science Publishers.

Marchetti, G. (2012). Against the view that consciousness and attention are fully dissociable. *Front. Psychol.* 3:36. doi: 10.3389/fpsyg.2012.00036

Marchetti, G. (2014). Attention and working memory: two basic mechanisms for constructing temporal experiences. *Front. Psychol.* 5:880. doi: 10.3389/fpsyg.2014.00880

Marchetti, G. (2018). Consciousness: a unique way of processing information. *Cogn. Process.* 19, 435–464. doi: 10.1007/s10339-018-0855-8

Martial, C., Cassol, H., Laureys, S., and Gosseries, O. (2020). Near-death experience as a probe to explore (disconnected) consciousness. *Trends Cogn. Sci.* 24, 173–183. doi: 10.1016/j.tics.2019.12.010

Mashour, G. A., Roelfsema, P., Changeux, J. P., and Dehaene, S. (2020). Conscious processing and the global neuronal workspace hypothesis. *Neuron* 105, 776–798. doi: 10.1016/j.neuron.2020.01.026

McLeod, P. D. (1977). A dual task response modality effect: support for multi-processor models of attention. *Q. J. Exp. Psychol.* 29, 651–667. doi: 10.1080/14640747708400639

Merker, B. (2013a). The efference cascade, consciousness, and its self: naturalizing the first-person pivot of action control. *Front. Psychol.* 4:501. doi: 10.3389/fpsyg.2013.00501

Merker, B. (2013b). "Body and world as phenomenal contents of the brain's reality model,"," in *The Unity of Mind, Brain and World, Current Perspectives on a Science of Consciousness*, eds A. Jr. Pereira and D. Lehmann (Cambridge: CUP), 7–42. doi: 10.1017/CBO9781139207065.002

Mesulam, M. M. (1990). Large-scale neurocognitive networks and distributed processing for attention, language, and memory. *Ann. Neurol.* 28, 597–613. doi: 10.1002/ana.410280502

Millière, R., Carhart-Harris, R. L., Roseman, L., Trautwein, F. M., and Berkovich-Ohana, A. (2018). Psychedelics, meditation, and self-consciousness. *Front. Psychol.* 9:1475. doi: 10.3389/fpsyg.2018.01475

Mindt, G. (2017). The problem with the 'information' in integrated information theory. *J. Conscious. Stud.* 24, 130–154.

Mingers, J., and Standing, C. (2014). *What is Information Such That There Can Be Information Systems? Working Papers* , Vol. 302. Canterbury: University of Kent, Kent Business School, 1–32.

Mobbs, D., and Watt, C. (2011). There is nothing paranormal about near-death experiences: how neuroscience can explain seeing bright lights, meeting the dead, or being convinced you are one of them. *Trends Cogn. Sci.* 15, 447–449. doi: 10.1016/j.tics.2011.07.010

Montaser-Kousari, L., and Rajimehr, R. (2004). Subliminal attentional modulation in crowding condition. *Vision Res.* 45, 839–844. doi: 10.1016/j.visres.2004.10.020

Morsella, E. (2005). The function of phenomenal states: supramodular interaction theory. *Psychol. Rev.* 112, 1000–1021. doi: 10.1037/0033-295X.112.4.1000

Mudrik, L., Faivre, N., and Koch, C. (2014). Information integration without awareness. *Trends Cogn. Sci.* 18, 488–496. doi: 10.1016/j.tics.2014.04.009

Munévar, G. (2020). A cellular and attentional network explanation of consciousness. *Conscious. Cogn.* 83, 1–9. doi: 10.1016/j.concog.2020.102982

Naccache, L., Blandin, E., and Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychol. Sci.* 13, 416–424. doi: 10.1111/1467-9280.00474

Nakayama, K., and Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision Res.* 29, 1631–1647. doi: 10.1016/0042-6989(89)90144-2

Nida-Rümelin, M. (2017). Self-awareness. *Rev. Philos. Psychol.* 8, 55–82. doi: 10.1007/s13164-016-0328-x

Noah, S., and Mangun, G. R. (2020). Recent evidence that attention is necessary, but not sufficient, for conscious perception. *Ann. N Y Acad. Sci.* 1464, 52–63. doi: 10.1111/nyas.14030

Northoff, G. (2013). What the brain's intrinsic activity can tell us about consciousness? A tri-dimensional view. *Neurosci. Biobehav. Rev.* 37, 726–738. doi: 10.1016/j.neubiorev.2012.12.004

Northoff, G., and Huang, Z. (2017). How do the brain's time and space mediate consciousness and its different dimensions? Temporo-spatial theory of consciousness (TTC). *Neurosci. Biobehav. Rev.* 80, 630–645. doi: 10.1016/j.neubiorev.2017.07.013

Northoff, G., and Lamme, V. (2020). Neural signs and mechanisms of consciousness: is there a potential convergence of theories of consciousness in sight? *Neurosci. Biobehav. Rev.* 118, 568–587. doi: 10.1016/j.neubiorev.2020.07.019

Nurse, P. (2008). Life, logic and information. *Nature* 454, 424–426. doi: 10.1038/454424a

Oberauer, K. (2009). Design for a working memory. *Psychol. Learn. Motiv.* 51, 45–100. doi: 10.1016/S0079-7421(09)51002-X

Oizumi, M., Albantakis, L., and Tononi, G. (2014). From the phenomenology to the mechanisms of consciousness: integrated information theory 3.0. *Comput. Biol.* 10:e1003588. doi: 10.1371/journal.pcbi.1003588

Orpwood, R. (2017). Information and the origin of qualia. *Front. Syst. Neurosci.* 11:22. doi: 10.3389/fnsys.2017.00022

Parr, T., and Friston, K. J. (2017). The active construction of the visual world. *Neuropsychologia* 104, 92–101. doi: 10.1016/j.neuropsychologia.2017.08.003

Pashler, H. E. (1989). Dissociations and dependencies between speed and accuracy: evidence for a two-component theory of divided attention in simple task. *Cogn. Psychol.* 21, 469–514. doi: 10.1016/0010-0285(89)90016-9

Pashler, H. E. (1998). *The Psychology of Attention*. Cambridge, MA: The MIT Press. doi: 10.7551/mitpress/5677.001.0001

Pepperell, R. (2018). Consciousness as a physical process caused by the organization of energy in the brain. *Front. Psychol.* 9:2901. doi: 10.3389/fpsyg.2018.02091

Pierson, L. M., and Trout, M. (2017). What is consciousness for? *New Ideas Psychol.* 47, 62–71. doi: 10.1016/j.newideapsych.2017.05.004

Pitts, M. A., Lutsyshyna, L. A., and Hillyard, S. A. (2018). The relationship between attention and consciousness: an expanded taxonomy and implications for 'no-report' paradigms. *Phil. Trans. R. Soc. B* 373:20170348. doi: 10.1098/rstb.2017.0348

Pockett, S. (2014). Problems with theories that equate consciousness with information or information processing. *Front. Syst. Neurosci.* 8:225. doi: 10.3389/fnsys.2014.00225

Pöppel, E. (1997). A hierarchical model of temporal perception. *Trends Cogn. Sci.* 1, 56–61. doi: 10.1016/S1364-6613(97)01008-5

Pöppel, E. (2004). Lost in time: a historical frame, elementary processing units and the 3-second window. *Acta Neurobiol. Exp.* 64, 295–302.

Posner, M. I. (1980). Orienting of attention. *Q. J. Exp. Psychol.* 23, 3–25. doi: 10.1080/00335558008248231

Posner, M. I., and Cohen, Y. (1984). "Components of performance," in *Attention and Performance X*, eds H. Bouma and D. Bowhuis (Hillsdale, NJ: Erlbaum), 531–556.

Posner, M. I., and Petersen, S. E. (1990). The attention system of the human brain. *Annu. Rev. Neurosci.* 13, 25–42. doi: 10.1146/annurev.ne.13.030190.000325

Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience* 139, 23–38. doi: 10.1016/j.neuroscience.2005.06.005

Prinz, J. J. (2011). "Is attention necessary and sufficient for consciousness?," in *Attention: Philosophical and Psychological Essays*, eds C. Mole, D. Smithies, and W. Wu (Oxford: Oxford University Press), 174–203.

Rabinovich, M. I., Afraimovich, V. S., Bick, C., and Varona, P. (2012). Information flow dynamics in the brain. *Phys. Life Rev.* 9, 51–73. doi: 10.1016/j.plrev.2011.11.002

Rochat, P. (2003). Five levels of self-awareness as they unfold early in life. *Conscious. Cogn.* 12, 717–731. doi: 10.1016/S1053-8100(03)00081-3

Roederer, J. G. (2003). On the concept of information and its role in nature. *Entropy* 5, 3–33. doi: 10.3390/e5010003

Roux, F., and Uhlhaas, P. J. (2014). Working memory and neural oscillations: alpha–gamma versus theta–gamma codes for distinct WM information? *Trends Cogn. Sci.* 18, 16–25. doi: 10.1016/j.tics.2013.10.010

Ruffini, G. (2017). An algorithmic information theory of consciousness. *Neurosci. Conscious.* 2017:nisx019. doi: 10.1093/nc/nix019

Safron, A. (2020). An Integrated World Modeling Theory (IWMT) of consciousness: combining integrated information and global neuronal workspace theories with the free energy principle and active inference framework; toward solving the hard problem and characterizing agentic causation. *Front. Artif. Intell.* 3:30. doi: 10.3389/frai.2020.00030

Safron, A. (2021). World modeling, integrated information, and the physical substrates of consciousness; hidden sources of the stream of experience?. *PsyArXiv* [Preprint]. doi: 10.31234/osf.io/aud6e

Searle, J. R. (1992). *The Rediscovery of the Mind*. Cambridge, MA: MIT Press. doi: 10.7551/mitpress/5834.001.0001

Sengupta, B., Stemmler, M., Laughlin, S. B., and Niven, J. E. (2010). Action potential energy efficiency varies among neuron types in vertebrates and invertebrates. *PLoS Comput. Biol.* 6:e1000840. doi: 10.1371/journal.pcbi.1000840

Senoussi, M., Moreland, J. C., Busch, N. A., and Dugué, L. (2019). Attention explores space periodically at the theta frequency. *J. Vis.* 19, 22–22. doi: 10.1167/19.5.22

Shulman, R. G., Hyder, F., and Rothman, D. L. (2009). Baseline brain energy supports the state of consciousness. *Proc. Natl. Acad. Sci. U.S.A.* 106, 11096–11101. doi: 10.1073/pnas.0903941106

Simione, L., Di Pace, E., Chiarella, S. G., and Raffone, A. (2019). Visual attention modulates phenomenal consciousness: evidence from a change detection study. *Front. Psychol.* 10:2150. doi: 10.3389/fpsyg.2019.02150

Skyrms, B. (2010). *Signals: Evolution, Learning, & Information*. Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780199580828.001.0001

Solms, M. (2019). The hard problem of consciousness and the free energy principle. *Front. Psychol.* 9:2714. doi: 10.3389/fpsyg.2018.02714

Song, K., Meng, M., Chen, L., Zhou, K., and Luo, H. (2014). Behavioral oscillations in attention: rhythmic alpha pulses mediated through theta band. *J. Neurosci.* 34, 4837–4844. doi: 10.1523/JNEUROSCI.4856-13.2014

Srinivasan, N. (2008). Interdependence of attention and consciousness. *Prog. Brain Res.* 168, 65–75. doi: 10.1016/S0079-6123(07)68006-6

Srinivasan, N. (2020). Consciousness without content or minimal content: a look at evidence and prospects. *Front. Psychol.* 11:1992. doi: 10.3389/fpsyg.2020.01992

Strawson, G. (1997). The self. *J. Conscious. Stud.* 4, 405–428.

Street, S. (2016). Neurobiology as information physics. *Front. Syst. Neurosci.* 10:90. doi: 10.3389/fnsys.2016.00090

Styles, E. A. (1997). *The Psychology of Attention*. New York, NY: Psychology Press. doi: 10.4324/9780203016435

Sumner, P., Tsai, P.-C., Yu, K., and Nachev, P. (2006). Attentional modulation of sensorimotor processes in the absence of perceptual awareness. *Proc. Natl. Acad. Sci. U.S.A.* 103, 10520–10525. doi: 10.1073/pnas.0601974103

Synofzik, M., Vosgerau, G., and Newen, A. (2008). Beyond the comparator model: a multifactorial two-step account of agency. *Conscious. Cogn.* 17, 219–239. doi: 10.1016/j.concog.2007.03.010

Tamber-Rosenau, B. J., and Marois, R. (2016). Central attention is serial, but midlevel and peripheral attention are parallel-A hypothesis. *Atten. Percept. Psychophys.* 78, 1874–1888. doi: 10.3758/s13414-016-1171-y

Theeuwes, J. (1991). Exogenous and endogenous control of attention: the effect of visual onsets and offsets. *Percept. Psychophys.* 49, 83–90. doi: 10.3758/BF03211619

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychol.* 135, 77–99. doi: 10.1016/j.actpsy.2010.02.006

Thompson, E. (2015). "Dreamless sleep, the embodied mind, and consciousness. The relevance of a classical indian debate to cognitive science," in *Open MIND: 37(T)*, eds T. Metzinger and J. M. Windt (Frankfurt: MIND Group), 1–19.

Tononi, G. (2008). Consciousness as integrated information: a provisional manifesto. *Biol. Bull.* 215, 216–242. doi: 10.2307/25470707

Tononi, G. (2012). The integrated information theory of consciousness: an updated account. *Arch. Ital. Biol.* 150, 56–90.

Tononi, G., and Koch, C. (2015). Consciousness: here, there and everywhere? *Philos. Trans. R. Soc. Lond. B Biol. Sci.*370:20140167. doi: 10.1098/rstb.2014.0167

Treisman, A. (2006). How the deployment of attention determines what we see. *Vis. Cogn.* 14, 411–443. doi: 10.1080/13506280500195250

Tulving, E. (1985). Memory and consciousness. *Can. Psychol.* 26, 1–12. doi: 10.1037/h0080017

Unsworth, N., and Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychol. Rev.* 114, 104–132. doi: 10.1037/0033-295X.114.1.104

van Boxtel, J. J. A., Tsuchiya, N., and Kock, C. (2010). Consciousness and attention: on sufficiency and necessity. *Front. Psychol.* 1:217. doi: 10.3389/fpsyg.2010.00217

van Lommel, P. (2013). Non-local consciousness: a concept based on scientific research on near-death experiences during cardiac arrest. *J. Conscious. Stud.* 20, 7–48.

Vandekerckhove, M., and Panksepp, J. (2009). The flow of anoetic to noetic and autonoetic consciousness: a vision of unknowing (anoetic) and knowing (noetic) consciousness in the remembrance of things past and imagined futures. *Conscious. Cogn.* 18, 1018–1028. doi: 10.1016/j.concog.2009.08.002

Vanhaudenhuyse, A., Thonnard, M., and Laureys, S. (2009). "Towards a neuro-scientific explanation of near-death experiences?," in *Intensive Care Medicine*, ed. J.-L. Vincent (New York, NY: Springer), 961–968. doi: 10.1007/978-0-387-92278-2_85

VanRullen, R. (2013). Visual attention: a rhythmic process? *Curr Biol.* 23, R1110–R1112. doi: 10.1016/j.cub.2013.11.006

VanRullen, R. (2018). Attention cycles. *Neuron* 99, 632–634. doi: 10.1016/j.neuron.2018.08.006

VanRullen, R., Carlson, T., and Cavanagh, P. (2007). The blinking spotlight of attention. *Proc. Natl. Acad. Sci. U.S.A.* 104, 19204–19209. doi: 10.1073/pnas.0707316104

Vicario, G. B. (2005). *Il Tempo. Saggio di Psicologia Sperimentale*. Bologna: Il Mulino.

Vosgerau, G., and Newen, A. (2007). Thoughts, motor actions, and the self. *Mind Lang.* 22, 22–43. doi: 10.1111/j.1468-0017.2006.00298.x

Walker, S. I., and Davies, P. C. (2013). The algorithmic origins of life. *J. R. Soc. Interface* 10:20120869. doi: 10.1098/rsif.2012.0869

Wang, Y., Wang, R., and Xu, X. (2017). Neural energy supply-consumption properties based on hodgkin-huxley model. *Neural Plast.* 2017:6207141. doi: 10.1155/2017/6207141

Winters, J. J. (2021). The temporally-integrated causality landscape: reconciling neuroscientific theories with the phenomenology of consciousness. *Front. Hum. Neurosci.* 15:768459. doi: 10.3389/fnhum.2021.768459

Wittmann, M. (2011). Moments in time. *Front. Integr. Neurosci.* 5:66. doi: 10.3389/fnint.2011.00066

Wu, W. (2011). Confronting many-many problems: attention and agentive control. *Nous* 45, 50–76. doi: 10.1111/j.1468-0068.2010.00804.x

Zalta, A., Petkoski, S., and Morillon, B. (2020). Natural rhythms of periodic temporal attention. *Nat. Commun.* 11:1051. doi: 10.1038/s41467-020-14888-8

Zoefel, B., and Sokoliuk, R. (2014). Investigating the rhythm of attention on a fine-grained scale: evidence from reaction times. *J. Neurosci.* 34, 12619–12621. doi: 10.1523/JNEUROSCI.2134-14.2014

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What if consciousness is not an emergent property of the brain? Observational and empirical challenges to materialistic models

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The nature of consciousness is considered one of science's most perplexing and persistent mysteries. We all know the subjective experience of consciousness, but where does it arise? What is its purpose? What are its full capacities? The assumption within today's neuroscience is that all aspects of consciousness arise solely from interactions among neurons in the brain. However, the origin and mechanisms of *qualia* (i.e., subjective or phenomenological experience) are not understood. David Chalmers coined the term "the hard problem" to describe the difficulties in elucidating the origins of subjectivity from the point of view of reductive materialism. We propose that the hard problem arises because one or more assumptions within a materialistic worldview are either wrong or incomplete. If consciousness entails more than the activity of neurons, then we can contemplate new ways of thinking about the hard problem. This review examines phenomena that apparently contradict the notion that consciousness is exclusively dependent on brain activity, including phenomena where consciousness appears to extend beyond the physical brain and body in both space and time. The mechanisms underlying these "non-local" properties are vaguely suggestive of quantum entanglement in physics, but how such effects might manifest remains highly speculative. The existence of these non-local effects appears to support the proposal that post-materialistic models of consciousness may be required to break the conceptual impasse presented by the hard problem of consciousness.

KEYWORDS

non-local consciousness, orch-OR, integrated information theory, global workspace theories, higher-order theories, re-entry and predictive processing, analytic idealism, interface theory of perception

What is consciousness?

The term "consciousness" means different things to different audiences. From a lay perspective, the fact of consciousness (here meaning *awareness*) is so self-evident that the only question that may arise is why anyone would consider consciousness to be mysterious in the first place, akin to asking a fish, "What is water?" From a scientific perspective, the unsolved mystery is how consciousness emerges from brain activity. How does a three-pound lump of tissue inside the skull give rise to a mind that is self-aware and enjoys subjective experience? In philosophy, which has debated the "mind-body problem" for millennia, many sets of assumptions have been proposed, ranging from materialism (i.e., all is dependent on or reducible to the physical) to idealism (i.e., ideas or thoughts make up fundamental reality). For mystics and others entranced by the esoteric traditions, the problem is not so much about the mind but how the physical world emerges from a non-physical "substance."

Over the past few decades, most scientifically oriented research on consciousness has studied consciousness as a controlled variable. They have reduced consciousness to simpler constructs, such as perception, and focused on comparisons in brain processes during conscious and unconscious conditions, the so-called "contrastive approach." In this approach, differences in brain activity are examined when the same stimulus is subjectively perceived versus when it is not (Baars, 2005). This search for the neural correlates of consciousness (NCC) is defined as the "minimum neuronal mechanisms jointly sufficient for any one specific conscious experience" (Koch et al., 2016). Experimental designs have used methods like stimulus masking (Shapiro et al., 1997; Simons and Chabris, 1999; Dehaene et al., 2001) or binocular rivalry (Leopold and Logothetis, 1999) to examine the brain activity associated with subliminal perception where information is not consciously perceived yet processed by the brain. Other approaches have relied on brain lesions (Hebb and Penfield, 1940), or, more recently, by artificially modulating brain activity in specific regions and networks intracranially, during neurosurgery, or non-invasively with transcranial magnetic/electric/ultrasound stimulation (Selimbeyoglu and Parvizi, 2010). Other authors have focused solely on states of unconsciousness during general anesthesia (Hudetz, 2012), epilepsy (Blumenfeld and Taylor, 2003), or sleep (Steriade et al., 2001). While a front line of research, the NCC approach has conceptual limitations. Mainly, the terms "consciousness" and "correlates" are enmeshed because brain events that co-vary with conscious experience can either be the experience's neural substrates, the prerequisites, or even the experience's neural consequences (Aru et al., 2012; de Graaf et al., 2012).

Several scientific theories of consciousness are primed to be tested experimentally instead of merely identifying correlations between conscious/unconscious events and brain activity. In the sections below, we briefly summarize the main neuroscience theories, referred to as physicalist or reductionist theories, most of which assume that consciousness emerges from the brain. While most physicalist theories aim to explain different aspects of consciousness, they often share similarities and have been recently grouped into four categories: higher-order theories (HOTs), global work-space theories (GWTs), integrated information theory (IIT), and re-entry and predictive processing theories (Seth and Bayne, 2022). Here, we follow this categorization and present a brief summary. However, a full review of each theory is beyond this article's scope (see Seth and Bayne, 2022, for a full review).

Physicalist theories of consciousness

Global work-space theories

Cognitive scientist Bernard J. Baars first proposed the GWT in 1983. GWT is a cognitive architecture inspired by artificial intelligence where a centralized resource is available through which specialized processors share and receive information (Baars, 2005; Baars et al., 2021). The theory is based on the observation that there are highly specialized brain regions that process information locally and unconsciously, such as the visual cortex. Conscious experience occurs once there is a distributed activity in other brain areas, that is, "broadcasting" to the system as a whole (Baars, 2005). The widespread access, operation, and coordination of specialized neural networks, which would otherwise operate autonomously, is coordinated by consciousness, involving mainly the frontoparietal network and high-frequency oscillatory rhythms (Baars, 2005).

Dehaene and colleagues have adjusted the GWT to account for new knowledge about the brain, the so-called "neuronal global work-space" (Dehaene et al., 2003). For example, global activity among work-space neurons is generated by excitatory neurons responding to sensory stimuli with long-range cortico-cortical connections. In turn, this global activity inhibits alternative activity patterns among the work-space neurons to prevent the conscious experience of other stimuli (e.g., attentional blink). This inhibition mechanism would allow the unified experience of consciousness (the composition and exclusion axioms in IIT). Supported by experimental findings in the context of the search for NCCs, this popular model suggests that (1) most of the brain's computations are performed in a non-conscious operation mode and that (2) conscious access must be distinguished from selective attention, (3) conscious perception may be characterized by a non-linear function that 'ignites' a network of distributed areas (a gradual increase in stimulus visibility accompanied by a sudden transition of the neuronal workspace into a pattern, i.e., the broadcasting), and (4) the selected information gains access to additional computations for conscious perception such as temporary maintenance, global sharing, flexible routing (Dehaene et al., 2014). The model predicts that measures of complexity, long-distance correlation, and integration of brain signals should provide reliable indices of conscious processing and has clinical applications (e.g., sleep, coma, anesthesia; Dehaene et al., 2014; Mashour et al., 2020). Some investigators have recently attempted to generalize the GWT to brain-inspired artificial architectures by implementing the GWT into deep learning algorithms (VanRullen and Kanai, 2021). GWT is promising as a model. However, it is unclear what determines when information is broadcasted to the whole (e.g., threshold) and what discriminates different types of subjective experiences within the GWT theory.

Higher-order theories

The HOTs family includes, for example, the self-organizing meta-representational account theory (SOMA; Cleeremans et al., 2020), the adversarial framework for probabilistic computation (Gershman, 2019), and the perceptual reality monitoring theory (Lau, 2019). In this view, consciousness is defined as a higher-order representation of lower-order representations. In other words, subjective experiences reflect higher brain orders like meta-representations, which have learned to describe and interpret the lower-order functions such as local modules specialized in processing specific information. In this sense, consciousness is the brain's unconscious, embodied, enactive, non-conceptual theory about itself (Cleeremans et al., 2020). While Gehrman's model interprets this view in terms of computations and algorithms, Lau's view is in terms of belief and epistemic justification on a subjective level. The NCCs for the HOTs generally consist in anterior regions of the brain, like the prefrontal cortex, reflecting their involvement in complex cognitive functions (Lau and Rosenthal, 2011).

The primary limitation of both GWTs and HOTs is that they do not account for the phenomenal differences between distinct subjective experiences (Seth and Bayne, 2022). Furthermore, neither GWTs nor HOTs have addressed the adaptative and evolutionary role of conscious experience (i.e., embodiment and environmental embeddedness; Seth and Bayne, 2022).

Integrated information theory

Integrated information theory is a mathematical approach based on phenomenology by first identifying the essential properties of consciousness, the so-called axioms: *intrinsic information* – each experience is specific, there is intrinsic information in the system that is associated with that experience that differs from alternative experiences, *information* – consciousness is composed of a specific set of specific phenomenal distinctions and is different from other possible experiences, *integration* – consciousness is unified with each experience being irreducible to non-interdependent components, and *exclusion* – consciousness is unique in content and spatio-temporal context (Tononi, 2015; Tononi et al., 2016). IIT infers the postulates or requirements for a physical system to be a physical substrate of consciousness from the axioms.

Integrated information refers to a system's constituents that are discriminated by their respective information. The whole cannot be reduced to the information of each part, called the "causal-effect power" (Oizumi et al., 2014). These irreducible maxima of additional integrated information generated by the system as a whole compared to its parts are termed and quantified as Φ ("phi") and affect the probability of its past and future states. The larger the Φ value, the more intrinsic cause-effect power the system has and the more conscious it is (Koch, 2018). Thus, any complex and interconnected physical system with these properties will have some level or quantity of consciousness, corresponding to the amount of intrinsic cause-effect power the substrate has. The content of a conscious experience is predicted to be structurally identical to the cause-effect structure of its physical substrate (Albantakis, 2020). So the more structurally complex the system is, the more structurally complex the experience is. IIT, therefore, provides a potential method to (1) assess whether a physical system constitutes a physical substrate of consciousness through its compliance with the postulates, (2) quantify the level of consciousness of that system, and (3) estimate its phenomenological structure in causal terms (Albantakis, 2020).

Unlike HOTs and GWT, progress has been made to assess the relevance of environmental embodiment for consciousness (i.e., consciously capturing the causal structure of a rich environment). For example, Haun and Tononi (2019) showed how this is useful for successfully navigating spacetime (Haun and Tononi, 2019). Albantakis et al. (2014) showed that this is an important driving force for organisms to develop highly integrated networks ("brains"), leading to an increase in their internal complexity (Albantakis et al., 2014). These concepts bring evolutionary context to the development of consciousness and the complexity of the brain.

Re-entry and predictive processing approaches

Re-entry theories were developed from the idea that "we are fooled into thinking that we know what we are conscious of" (Lamme, 2010, p. 204). Therefore, introspective or behavioral observations make understanding the mind-brain relationship impossible. Thus, this approach removes intuitive or psychological notions of conscious experience from the study of consciousness (Lamme, 2006). In the local recurrency theory, conscious perception corresponds to top-down signaling (Lamme and Roelfsema, 2000; Lamme, 2006; Seth and Bayne, 2022). Consciousness emerges from simple localized recurrent, top-down processing within perceptual cortices, and frontal and parietal regions would be crucial to perceptual experience content, reasoning, and decision making (Lamme and Roelfsema, 2000; Lamme, 2006, 2010). Local recurrency theory is similar to GWTs, except that we do not know what we are conscious of and that it is about perception. In contrast, GWT is about access (Lamme, 2010).

Predictive processing approaches in computational neuroscience, such as the hierarchical generative model, consider the brain as a machine that matches bottom-up inputs with top-down expectations through cortical processing, aiming to minimize the error in these predictions (Clark, 2013). In this bi-directional model, top-down connections from higher levels encode the predictions in the lower levels. This fully explains the bottom-up signal and leaves only residual prediction errors propagating information forward in the system to update the following predictions (Huang and Rao, 2011; Clark, 2013). This predictive control function is termed "active inference" (Seth and Bayne, 2022).

The adaptive resonance theory (ART) was developed by Stephen Grossberg and Gail Carpenter to address the "stability-plasticity dilemma," or how the brain learns so quickly and stably without forgetting past knowledge (Grossberg, 2013a). For ART, various brain processes are required, namely Consciousness, Learning, Expectation, Attention, Resonance, and Synchrony (the CLEARS processes). Top-down expectations (E) direct the focus of attention (A) across competitive features. When a match occurs between the expectation and what is perceived, a resonant synchronization (RS) occurs and generates attentional focus driving fast learning (L) of bottom-up, called "many-to-one maps," and top-down, called "one-to-many maps" representations. This whole process is called "adaptive resonance." Here, the focus of attention corresponds to the minimization of error in the prediction function. There is growing experimental data supporting these predictions, and some ART models are thought to explain and predict behavioral, anatomical, neurophysiological, and biochemical data (Grossberg, 2013b).

In brief, for this family of theories, perceptual experience is the brain's best guess of its cause (minimization of the prediction error) through the exchange of top-down predictions and bottom-up prediction errors (Rao and Ballard, 1999; Friston, 2010; Hohwy, 2013; Seth and Bayne, 2022). For example, subjective emotions are considered to emerge from cognitive evaluations of physiological changes in the body and their causes ("constructed emotion" and "interoceptive inference"; Seth, 2013; Barrett, 2016).

Summary of physicalist models

One common element across physicalist theories is the uncertainty reduction that results from allocating mechanisms to consciousness. The system must settle into one unified and highly informative representational state (Hohwy and Seth, 2020). This point of uncertainty reduction often corresponds to a threshold at which the contents become conscious (e.g., broadcasting for GWT, optimization of signal-to-noise ratio for HOTs, φ for IIT, information integration, and learning for re-entry and predictive theories). The second common element is the high importance of top-down signaling (e.g., a system with no top-down dimension has no φ in IIT; Oizumi et al., 2014).

The first disagreement between these theories regards the distinction between consciousness and cognition. Cognitive access relies on consciousness in GWT, consciousness is cognitively accessible in HOTs, whereas cognition is possible without consciousness for IIT and vice versa for predictive processing and re-entry theories. The second, more critical, disagreement between physicalist theories is in regards to the unity of consciousness, i.e., the subjective experience of awareness that fully captures what it is like to be an agent at any time. It is required by IIT and may be supported by the broadcast in GWTs but is ignored by HOTs, re-entry, and predictive theories that do not consider this concept necessary. These various theories may, in fact, address different aspects of consciousness.

In the well-known parable, "The Blind Men and the Elephant," each person attempts to describe the elephant but only touches one small part (Saxe, 2016). Thus, they arrive at very different conclusions about what an elephant is like: a tree, a fan, a rope, a spear. They commence arguing, each one convinced that they are correct in their conclusions. The story's moral is that we must step back to observe broader perspectives to describe and fully understand the elephant's nature. Similarly, these physicalist theories may describe some aspects of consciousness very well, but they likely do not describe it completely.

In conclusion, while extensive and rigorous efforts have attempted to find, test, and validate physicalist theories or NCCs (Reardon, 2019; Templeton World Charity Foundation, 2022), the field is far from consensus about which theories are valid and could potentially explain consciousness or neural differences between different phenomenological experiences. We suggest that the gaps in physicalist theories in explaining consciousness may arise because the debate is framed around how the brain *generates* consciousness. The theories discussed so far attempt to explain phenomenological experience or qualia through reductionist brain mechanisms or correlations, often equated to computational or information processing systems. Some of these theories (e.g., re-entry or predictive processing theories) even consider subjective reports and introspection to be unreliable. Consequently, none of these theories have completely and convincingly explained the nature of consciousness.

A different approach: Non-local consciousness theories

Alternative non-physicalist theories may inform other aspects of consciousness that are not completely explained by physicalist theories. Physicalist theories usually assume that consciousness is generated solely and purely from the brain and is only local to the brain. Alternatively, non-physicalist theories do not make these assumptions, even though both types of theories attempt to explain the underlying brain mechanisms of consciousness. Physicalist theories purport that consciousness originates from physical substrates like neurons that have evolved to be more and more complex over time through adaptation, leading to the emergence of consciousness. Non-physical models do not assume a physical substrate generates consciousness, and many even propose that consciousness is, in fact, more fundamental than matter and spacetime. In this view, that is the natural view for most ancient and eastern cultures, matter and spacetime arise from consciousness rather than the other way around. Perhaps a non-physicalist framework where consciousness is considered fundamental and has non-local properties (such as at the quantum scale) would better explain the full range of reported human phenomenology. For example, there are well-documented experiences of people perceiving information from distant locations, the future, and mental impressions from other people without the use of rationale or traditional means (Cardeña, 2018). In addition, there are verified cases of cognitive function when the neural substrate is severely degenerated, precluding normal brain function. These experiences, most of which are currently regarded as anomalous, will be described in the Section "Phenomena suggested by a model of nonlocal consciousness" as cases of what would be observed should non-physicalist theories of consciousness be valid.

These and other documented phenomenological experiences suggest a different nature of consciousness: one that may not be exclusively generated by neuronal activity and exhibits properties that transcend the conventional constraints of spacetime and, therefore, the physical body. The term "non-local consciousness" has been proposed to denote these purported transcendent properties of consciousness (Dossey, 1994). Physicalist scientists typically consider such experiences anomalous because they challenge prevailing assumptions about the nature and role of consciousness in physical reality. The term non-local is also referenced as a central idea within physics as an aspect of the physical world. For example, the brain operating, even to a small extent, in a quantum fashion might be a valid explanation for these non-local phenomena. However, this idea is not yet widely accepted because while there is evidence for quantum biology, quantum coherence in brain processing is so short-lived that it appears irrelevant to understanding consciousness. Neuroscience today says consciousness is generated by and localized in the brain because it emerges from brain activity. Alternatively, we propose that consciousness may not originate in the brain, although some aspects of human perception of consciousness may be dependent on the brain. We also suggest that awareness also extends beyond the brain. These non-physical, non-local properties of consciousness may be due to a non-local material effect, to consciousness being fundamental, or something else we have not yet discovered.

To begin an exploration of some of these non-physical theories, we present theoretical frameworks proposed by scientists from multiple disciplines, most of which include the idea that consciousness is fundamental, meaning that consciousness precedes the physical substrates (Chalmers, 1996; Currivan, 2017; Kastrup, 2017, 2021; Goff, 2019; Faggin, 2021a). Traditional materialists envision a world in which mathematics is more fundamental than physics, which is more fundamental than chemistry, which is, in turn, more fundamental than biology. Thus, in this way, physical processes are foundational to the generation of our biology. However, suppose we envision that consciousness is actually more foundational than physics. In that case, we can imagine that these other physical disciplines can arise from consciousness. In other words, if biology emerges from chemistry, chemistry from physics, and physics emerges from consciousness, then from this perspective, non-local consciousness phenomena would no longer be regarded as anomalous because consciousness can transcend some physical laws. Theories proposing this idea have been offered by Federico Faggin, Donald Hoffman, Bernardo Kastrup, Vernon Neppe, and numerous others. Most of these theories are speculative, while others are supported through mathematical arguments or empirical data (Hoffman et al., 2015; Neppe and Close, 2020; Faggin, 2021b). We briefly review a sample of non-local consciousness theories.

Operational probabilistic theory

Federico Faggin starts with the assumption that reality emerges from the free-will communications of a vast number of conscious entities (Faggin, 2021a). Faggin calls the totality of what potentially and actually exists, *One.* Any self-knowing within this *one* is a transformation from potential existence into actual existence, where potential existence is the "reservoir" of self-knowing that has not yet manifested. Each new self-knowing brings rise to a *consciousness unit (CU).* The CU reflects the whole of *One* and is also part of *One* because *One* is never complete in its self-knowing process. Thus there must be continued self-knowing and continual generation of CUs, which explains an apparently growing number of conscious entities (Faggin, 2021a, p. 294). Faggin describes the CUs characteristics and how they combine into *self*, in which an entity with identity, awareness, and agency is dynamic, holistic, and self-knowing. Faggin views the physical world as a virtual reality metaphor, in which sophisticated avatars controlled by conscious beings interact with each other, where the body that controls the avatar exists outside the computer and is not part of the program. Similarly, the conscious entities that control physical bodies exist beyond the physical world that contains the body (Faggin, 2021b, p. 286).

Interface theory of perception

Donald D. Hoffman proposes a model based on a mathematical structure called "conscious agents." Space and time emerge from conscious agents' exchanges (Hoffman, 2014). Hoffman proposes that our perceptions (i.e., the conscious agents) are not views of a grounded truth but are more like a personal computer's operating system and interface (Hoffman, 2014, 2019). Perceptions allow us to interact dynamically with the world and survive and evolve in this environment but not be aware of its actual structure. Space-time and physical objects do not represent a universal objective reality but are species-specific components that provide an evolutionary advantage. Hoffman highlights that evolutionarily, perception of spacetime and the physical world are shaped by natural selection in such a way that obfuscates the truth that we are experiencing an interface rather than a universal objective reality and thus influences adaptive behaviors. He further claims that the equations of quantum mechanics can be derived from formalized descriptions of the interactions between conscious agents (Hoffman et al., 2015).

Analytic idealism

Bernardo Kastrup proposes "analytic idealism" as a model for reality, in which the ground of existence is universal phenomenal consciousness (Kastrup, 2021). Analytic idealism is a metaphysics that postulates consciousness as Nature's sole fundamental ground and that all natural phenomena are ultimately reducible to universal consciousness. He describes phenomenal consciousness as a raw subjective experience of awareness that differs from cognition, meta-cognition, self-awareness, or other higher mental functions. Meta-cognition allows humans to know that they are having an experience and also supports cognitive properties like reasoning and planning. Experiential consciousness or pure awareness can also occur without meta-cognition, as reported in classical mystical states. Because there is only one universal consciousness, individuated living beings are described as dissociated mental complexes of the "fundamentally unitary universal mind" (Kastrup, 2021, p. 267). This dissociation creates a subjective private inner world that can perceive itself as interacting with the transpersonal world. Matter in this model is described as the outward appearance of the inner experience as observed from across the dissociative boundary. Put another way,

> *As experienced from the inside—that is, from the first-person perspective—each living being, plus the inanimate universe as a whole, is a conscious entity. But as experienced from outside—that is, from a[n illusory] second- or third-person perspective—our respective inner lives present themselves in the form of what we call matter, or physicality. . .all matter—is merely the name we give to what conscious inner life looks like from across its dissociative boundary. (Kastrup, 2021, pp. 267–268)*

Triadic dimensional vortical paradigm

Vernon Neppe and Ed Close propose that the standard 4-dimensional model of physics (three dimensions of space and one of time) results in many contradictions or unexplained discrepancies (see Neppe and Close, 2020 for examples of apparent discrepancies). For example, using the Diophantine equation (a polynomial equation involving two or more unknowns and in which only integer solutions are allowed), Neppe states that the mass/energy of up-quarks and down-quarks produces an inequality that is unstable (Neppe and Close, 2015). To address these discrepancies, Neppe and Close describe a mathematical model in which we exist in a 9-dimensional finite, quantized, volumetric, spinning reality embedded in an infinite continuity (9D+). The model requires an extra component that they dub "gimmel," which is mass and energy less. Close expresses that "gimmel is the connection between consciousness, life, and the atomic structure and that the potential for conscious life existed in the mutable mass and energy of quarks even before they became the first protium atoms of physical reality" (Close, 2018). The model proposes that the 4D world we ordinarily experience is the physical component of this 9D+ existence. Neppe and Close believe that the model has been empirically demonstrated with correspondences to normalized data for the mass-energy equivalence volumetric data for measured particles. They also claim that their model is mathematically valid at the micro, macro, and cosmological scales.

> *Mathematically, gimmel necessarily has to exist in union with any particle in the universe for that particle to be stable. Without gimmel, the spinning (vortical) atoms would be unstable and asymmetrical about their axes and would, in effect, fly apart: Our world and the physical universe could not exist. (Neppe and Close, 2020, p. 4)*

Zero-point field

Joachim Keppler (2018) proposes a theory where the energy of the vacuum is the basis for consciousness, the so-called "zero-point field" (Keppler, 2018). This is a theory of panpsychism where consciousness permeates the universe yet is only concentrated and apparent in certain circumstances. Unlike other panpsychism theories, it is not the "matter" that is conscious but empty space. However, the idea that matter is conscious may be incompatible with theoretical physics. If matter is conscious, particles may have the yet unknown property "consciousness." Mathematically, particles are elementary because they cannot be assigned additional parameters than those currently assigned (e.g., a charge, spin, mass). Therefore, the idea that they are conscious is challenging to reconcile with physics. The zero-point field does not have the same problem. Keppler hypothesizes that the human brain is one of the physical mediums which can interact directly with the zero-point field by concentrating on it and thus experiencing consciousness. The details of this putative interaction are not currently known. However, the interesting element of this theory is that it leads to testable predictions, e.g., interactions between the brain (maybe through quantum phenomena as in the Orch OR theory), and the zero-point field could possibly be observed and measured. For example, there might be specific types of photon exchanges that would reveal this interaction.

Orchestrated objective reduction theory

The Orch OR theory was developed by Stuart Hameroff and Sir Roger Penrose (Hameroff, 2021; Hameroff and Penrose, 2014). While the Copenhagen interpretation posits that the collapse of quantum states into a single state (the so-called "collapse of the wave function") is determined by an observation (i.e., subjective reduction), Penrose's objective reduction (OR) posits that it occurs when the energy difference (measured by spacetime curvature and mediated by gravity) of these states reaches an objective threshold (called the "Diósi–Penrose criterion"). Random proto-conscious moments of experience occur at each OR moment (Hameroff, 2021, p. 74). At the biological level, this OR would be orchestrated (Orch) by connective proteins (e.g., microtubule-associated proteins; MAPs) that influence this spacetime-separation of the qubits' superimposed states. These quantum processes are performed by qubits formed on cellular microtubules by oscillating dipoles (the microtubule condensate), forming superposed resonance rings in helical pathways throughout the microtubule lattices. These oscillations are either electric or magnetic and are then amplified by neurons, leading to consciousness. This collective process corresponds to the orchestration of the objective reduction of quantum states in the brain (Orch-OR). The microtubules both influence and are influenced by the conventional synaptic activity of neurons. Hameroff later added that the condensates might travel across more considerable distances in the brain through dendritic-dendritic gap junctions (connections that allow much faster transfer of action potentials than synapses), generating gamma oscillations (high-frequency brain rhythms) associated with conscious perception, for example. This theory provides a straightforward mechanism that can be tested more easily than others. Experiments are underway to test the theory by evaluating if the proposed quantum interference is, in fact, present in microtubules and dampened by anesthesia (Kalra et al., 2020).

Schooler hypothesis of subjective time

Psychologist Jonathan Schooler proposes subjective time as a new dimension of physics that would allow us to have a causal effect on the world (Schooler, 2014). This model proposes that one could conceive of the possibility of alternative dimensions of meta-perspective where each of us could move across time and raises the possibility that consciousness itself could have some causal role. In his model, a hierarchical cascade of conscious elements would have synchronization happening essentially like carrier waves. The lower level of waves has a particular rhythm. They are also synchronized, or cross-coupled, with the higher levels. In the same way that you can have very high-frequency waves or vibrations synced in with lower-frequency ones, in a sort of cross-coupling manner, you could also have the rhythms of the lower-level ones connected up to the higher-level ones. Through cross-frequency coupling, there potentially exists both top-down and bottom-up paths, explaining consciousness at a macroscopical level.

Theory of double causality

Philippe Guillemant, a theoretical physicist, has proposed that trajectories between two spacetimes are not fixed within the block universe (Guillemant and Medale, 2019). The block universe is a model where the future is already realized and is implied by general relativity. Within this framework, Guillemant proposes a non-deterministic model of the block universe where consciousness and free will are mechanisms by which the exact path between two spacetime points is decided. He shows that this does not contradict the equations of physics. He also suggests that the irreversibility of time as we experience it might not be a fundamental property of the world but a statistical one. Statistically, time moves forward, but there might be rare instances where it could move backward. Similarly, he suggests that there might be future traces in the present. Although statistically, we will mostly see causal traces of the past, future traces may be experienced as observations of coordinated systems that past observations cannot explain. For example, one might observe an organized pattern that is not due to a specific causal effect in the past. In his model, he argues that the organization must come from the future as it has no causal past reason to exist. He states, "We can carry on doing physics, but we must be absolutely logical about it, considering our intentions as physical realities, with the added ingredient that they do not appear to depend solely on our brains but also on an information system outside spacetime" (Guillemant, 2016, p. 9).

Summary of non-local consciousness models

Most of these theories assume that consciousness is fundamental and primary to all else. Our subjective intersection with this fundamental consciousness is described in different ways, such as being an interface, a dissociative boundary, or a consciousness unit. Moreover, the mechanistic structure of our world with consciousness as fundamental is explained in various ways (e.g., dimensions, conscious agents, *gimmel).*

However, it is important to note that physicalist theories still have a place in this framework. Even if consciousness is fundamental, these theories will inform on the mechanisms for the embodiment of consciousness into this materialistic reality (e.g., how the interface works). If we can perceive non-local information (as observed at the quantum scale), we likely still need to filter out the noise from the environment through uncertainty reduction, broadcast, and top-down processes for that information to become conscious. Predictive processes and updating the error prediction might be a crucial process to allow the perception of non-local information.

Another important point is that the IIT model could be a tool to study both physicalist and non-local theories of consciousness by including non-local properties into the spacetime postulates. In Section "Physicalist theories of consciousness," we placed IIT as a physicalist theory of consciousness in the sense that it excludes non-local spacetime properties into the spacetime boundaries required for a physical system to be conscious, and all models are based on the conventional assumptions of spacetime. However, since IIT is only about information and systems, one may be able to test IIT for non-local consciousness. Spacetime properties could be included in the postulates (i.e., requirements for a physical substrate to be conscious) for the calculation of φ (e.g., quantum links between past and future) to see how this addition affects φ's value. These non-local applications of ITT would allow for the non-local effects observed in quantum mechanics and the literature reviewed in Section "Phenomena suggested by a model of nonlocal consciousness."

Just like physicalist theories need rigorous testing to validate them, non-local consciousness theories also need testing and validating. The key to fully validating a theory of consciousness (physicalist or non-local) is to make a prediction that can be experimentally tested and quantified, thus, validating or invalidating the prediction. Theories that cannot meet the prediction can be rejected or adjusted. Unfortunately, many theoretical predictions are challenging to test experimentally, and sometimes prediction confirmation might depend on future technological innovations. Often, the theory is built with abstract terms that need further precision and elaboration. The more precise the theory and the prediction, the more it lends itself to testing. Also, the theory may be demonstrated with mathematics and yet not currently be experimentally validated.

One very small step to explore the applicability of the concept of non-local consciousness models and the motivation for developing these models in the first place is driven by phenomena that are not accounted for by physicalist theories, as described in the next section. One reason that non-local consciousness models may be useful is that they allow for the possibility of the subjective experiences that are usually considered impossible by physicalist models or simply ignored because of the basic assumptions on which they are built.

Phenomena suggested by a model of non-local consciousness

In the next section, we propose specific phenomena that we would expect to see if non-local consciousness theories are correct.

Phenomenon #1: Perceiving information about distant locations

If consciousness were non-local, then an individual ought to be able to perceive information beyond the reach of the brain, body, and senses. For example, one might be able to gain information about a person, place, or object at a distant location. Such abilities are described as part of a classified US government program that ran from 1972 to 1995, which sought to use non-local consciousness for espionage (May and Marwaha, 2018). That program conducted over 500 operational missions, some of which are said to have resulted in actionable intelligence and also several hundred controlled experimental trials. The latter was evaluated by a professor of statistics and skeptical psychology professional. Both concluded that the evidence in those studies was statistically significant and could not be attributed to methodological flaws (Mumford et al., 1995; Utts, 2016). In a typical experimental session, a "viewer" would enter a relaxed state. An interviewer would give them a random number designating the desired target and then ask them to describe and/or draw any information they perceived about that target. Both viewer and interviewer were blind to the target. Multiple meta-analyses of public domain and declassified experiments of this type have been conducted, and the results showed highly positive evidence in favor of a genuine phenomenon (Milton, 1997; Dunne and Jahn, 2003; Baptista et al., 2015; Cardeña, 2018). This apparent ability is now used for other practical applications, such as predicting stock market movements (Harary and Targ, 1985; Kolodziejzyk, 2013; Smith et al., 2014), locating missing persons (Mcmoneagle and May, 2004), and finding previously unknown archaeological sites (Schwartz, 2005, 2019).

Phenomenon #2: Perceiving information from another person

If consciousness were non-local, an individual might be able to receive information about another, isolated person's mental activity from a distance. Numerous well-controlled laboratory studies have observed this apparent phenomenon using the *ganzfeld* protocol, one of the most-repeated non-local consciousness studies. Ganzfeld originates from a German word meaning "whole field," and Gestalt psychologists initially developed the protocol. First, a person is exposed to low-level, unpatterned sensory stimuli (e.g., red light diffused to the eyes and white noise played through headphones). Meanwhile, a second, isolated person attempts to mentally "send" a target image randomly selected out of a pool of four possible images, which was randomly selected out of a database of many such pools. The chance of the "receiving" person correctly selecting the actual image is thus 25%. Over 120 published experiments have used this protocol, comprising about 4,000 individual trials, and the overall hit rate was just over 30%. Multiple reviews and meta-analyses on this protocol have also been conducted (Storm et al., 2010; Baptista et al., 2015; Cardeña, 2018; Storm and Tressoldi, 2020). These results have been discussed and debated in one of the principal journals in academic psychology, *Psychological Bulletin* (Bem and Honorton, 1994; Hyman, 2010; Storm et al., 2010).

In a conceptually similar design, rather than testing whether one person could select a correct image sent by another isolated person, the person's unconscious physiological state was intentionally influenced by a second person who was asked to focus their attention on them. These studies have typically used measures such as electrodermal activity (Braud and Schlitz, 1983; Radin et al., 2008), electroencephalography (EEG) activity (Standish et al., 2004; Richards et al., 2005), and functional magnetic resonance imaging (Standish et al., 2003; Achterberg et al., 2005). To date, there have been three meta-analyses for this class of studies, with each reporting statistically significant outcomes (Schmidt et al., 2004; Schmidt, 2012, 2015). Using this experimental paradigm, researchers discovered that the prior beliefs of the investigators were an important element in the observed outcomes. That is, working with the same subject populations, protocol, equipment, and analyses, skeptical investigators obtained null results, but investigators more open to the possibility of an effect obtained significant results (Watt et al., 2002; Schlitz et al., 2006). These investigator-specific effects have been documented in psychology and are called "experimenter effects" (Palmer and Millar, 2015). Thus, it is challenging to ascertain if results are solely influenced by the experimenter effect (i.e., intentions of the investigator) or if there are intrinsic effects. Multiple-experimenter studies have been posed as a solution to solving this issue in psychological studies (Bierman and Jolij, 2020).

Phenomenon #3: Perceiving the future

If consciousness were non-local, one might be able to perceive information from non-inferable future events. Experiments testing this idea have shown that people's physiology has reacted to randomly selected future events (Radin and Pierce, 2015), including electrodermal (Radin, 1997) and electrocortical activity (Radin and Lobach, 2007; Radin and Borges, 2009; Radin et al., 2011), and heart rate (McCraty et al., 2004; Tressoldi et al., 2009). These laboratory studies apparently demonstrate that the body can react to randomly selected stimuli approximately 1–10 s in the future. Erotic and negative images produce more robust responses than emotionally neutral pictures, and pre-responses generally manifest in the same direction as the body would typically respond after exposure to a stimulus. Meta-analyses have evaluated multiple laboratory studies with positive effect sizes (Mossbridge et al., 2012, 2014; Storm et al., 2012; Mossbridge and Radin, 2018; Honorton et al., 2018). For example, Mossbridge et al. (2012) analyzed 26 studies where unpredictable stimuli were presented and physiological activity was collected before, during, and after the stimuli. There was a pre-stimulus effect demonstrating a physiological response prior to the unpredictable stimuli (fixed effect: overall effect size = 0.21, 95% CI = 0.15 – 0.27, $z = 6.9$, $p < 2.71 \times 10^{-12}$; Mossbridge et al., 2012).

Implicit bias tests with a retrocausal element provide similar findings. In one paradigm, a classic perceptual priming task was reversed, such that the prime occurred after the target images. For example, in one task, the prime "happy" might typically occur prior to the target picture of a flower. In a reverse priming task, the flower image would appear *before* the prime "happy." These reverse priming tasks found slower response times when the prime/target pairs were incongruent (sad/flower) versus congruent (happy/flower), just as the classic task would, even though the prime occurred *prior* to the target. Some 90 independent replications of these experiments have provided evidence for a highly significant effect (overall effect size = 0.09, $z = 6.4$, $p = 1.2 \times 10^{-10}$; Bem et al., 2015).

Phenomenon #4: Apparent cognitive abilities beyond the experience/learning/skill of the person exhibiting them

If consciousness were non-local, then people might be able to gain cognitive skills without previous experience or training in those skills.

An example is the phenomenon of a person speaking a language unknown to, or xenoglossy. This phenomenon has been reported since ancient times. It refers to the ability of an individual to speak or write a language that they presumably did not know and could not have acquired by ordinary means. For example, in 400 BC, Plato mentions priestesses on the Island of Delos who spoke "in tongues." There are also descriptions in the Bible (Corinthians 14:1-40 and Acts 2:4).

Another example is Indriði Indriðason (1883–1912), who apparently spoke multiple languages he did not know (Haraldsson, 2012). Similarly, Alec Harris spoke at length to witness Sir Alexander Cannon in Hindustani and Tibetan, two languages that Harris would have had no way of knowing, but Sir Alexander did know (Vandersande, 2008, p. 113). Other xenoglossy cases have also been documented by University of Virginia scientist Ian Stevenson (Stevenson and Pasricha, 1979, 1980). While anecdotal and subject to the known biases of experiential reports, these cases have been meticulously well-documented. Similar cases of "acquired" and "spontaneous savants" refer to individuals who, either through a traumatic event or with no apparent cause at all, suddenly gain exceptional musical or mathematical skills (Treffert, 2009).

Phenomenon #5: Non-local consciousness experiences are common

If consciousness were non-local, such experiences would be highly prevalent in all humans. And indeed, non-local experiences can be found throughout history, across all cultures, and at all educational levels. Formal prevalence studies have been conducted for almost 50 years, with rates ranging from 10% to 97%, depending on the population surveyed (Bourguignon, 1976; Palmer, 1979; Haraldsson, 1985, 2011; Greeley, 1987; Haraldsson and Houtkooper, 1991; Ross and Joshi, 1992; McClenon, 1993; Cohn, 1994; Castro et al., 2014; Wahbeh et al., 2018). Another survey of the general public, scientists, and engineers in the United States found that over 90% had experienced at least one of 25 of these experiences (Wahbeh et al., 2018). With prevalence rates being well-above 10% of most populations surveyed, it is evident that these phenomena, at least in their subjective reports, are more frequent than commonly supposed.

Phenomenon #6: Cognitive abilities can be retained when the brain is seriously compromised

We usually assume that the brain is the body's driver, and if the brain is not working well, the body should not work. Suppose this is wrong and consciousness is not entirely dependent on the physical function of the brain. In that case, cognition, perception, and memory may continue to operate normally even when the brain would not be considered functional. This is consistent with what we see in a phenomenon called *terminal lucidity*. Terminal lucidity is a label given to a phenomenon in which patients with terminal neurodegenerative conditions display apparently normal cognitive function and mental clarity during the period preceding death (hours to days). While such experiences would seem impossible based on known principles of neuroscience and neuroanatomy, they have been reported in the medical literature for over 250 years (Nahm et al., 2012).

Terminal lucidity, also called paradoxical lucidity, has occurred in conditions such as waking from a long-term coma, dementia due to advanced Alzheimer's disease, brain abscesses, tumors, strokes, and meningitis (Nahm et al., 2012). A recent study of terminal lucidity reviewed 124 cases in dementia patients and found that in "more than 80% of these cases, complete remission with the return of memory, orientation, and responsive verbal ability was reported by observers of the lucid episode" (Batthyány and Greyson, 2021). For example, one reported case involved a patient with cancer that had metastasized to the brain, with little functional brain tissue remaining. However, an hour before the patient died, he regained awareness and conversed with his family for about 5 min before passing away (Nahm et al., 2012). Most terminal lucidity cases are retrospective case reports (Kelly et al., 2007; Nahm and Greyson, 2009; Nahm et al., 2012; Mashour et al., 2019; Batthyány and Greyson, 2021), but a few are prospective. Macleod and colleagues prospectively observed terminal lucidity cases (Macleod, 2009), as did Fenwick and colleagues (Fenwick et al., 2010). In these cases, the patients demonstrated normal cognitive abilities just prior to death, contrary to what objective medical findings would have predicted (e.g., EEG, neuroimaging). These patients are operating in an anomalous manner that brings into question the idea that the body is a "puppet" controlled from the inside (the brain) and that perhaps it can function alternately in some instances. Perhaps there are aspects of consciousness that could be "outside" of the body controlling it. The lucid mental functioning associated with these patients' behavior is challenging to explain under the assumption that one's sense of identity, memory, and awareness solely depends on brain activity.

Summary

In sum, we presented six phenomena regarding aspects related to non-local consciousness. Reports of individuals perceiving information from distant locations, from another person, from the future, where people gain skills beyond their normal capacity, or when the brain is apparently non-functional, have been documented in anecdotal and experimental contexts. In addition, these phenomena are ubiquitous worldwide. Note that these examples are not meant to provide definitive evidence for non-local consciousness, nor provide a comprehensive list of such phenomena, but rather to highlight that certain commonly reported phenomena, and some rare effects, present clear challenges to prevailing physicalist models of consciousness.

Of course, given the significant theoretical importance of these phenomena, each example supporting these predictions has evoked critical responses. The critiques have tended to fall into two classes. First, the phenomena suggested by these examples are deemed impossible because they violate the basic limiting principles of science. Therefore, the only possible way to interpret experiments reporting positive results is that they most likely involve flaws, fraud, or both. Critical reactions to anecdotal reports have also tended to focus on their subjective nature and the many ways that such experiences can be misinterpreted as illusions, misperceptions, or distorted memories. Such critiques can be answered by pointing out that some of the anecdotal reports involved hundreds to thousands of documented case studies, and all the experiments mentioned involved controlled experimental paradigms that were repeated in multiple laboratories and dozens to over a hundred independent replications, with overall highly significant meta-analytic outcomes (Cardeña, 2018). In some of the earliest experiments, methodological flaws were discovered but later corrected with similar results, so insisting that flaws or fraud can be the only possible explanations is not supported by analysis of the data.

The second category of critique is that perhaps the results could be accounted for by one or more physicalist explanations that we do not understand yet, given the state of the science. For example, perhaps some material explanation will eventually arise for how someone with severe brain atrophy and neurofibrillary tangles, or who was in a deep coma for an extended period, could nevertheless suddenly become lucid and maintain a coherent conversation with loved ones shortly before death. Alternatively, perhaps if it is established that the brain has quantum biological properties, then that might provide a plausible substrate for perceptual non-locality. That is, a brain that is partially acting in a quantum manner could possibly account for all these anomalous phenomena. A quantum brain would have non-local properties, so our sensory system would be spread out in space and time, and it might also have observational properties. However, even if this was true, it would not tell us anything about the nature or source of our subjective awareness. That is, from the quantum brain perspective, these phenomena would be completely explained as a purely physical phenomena (albeit within the context of the not-quite-physical nature of the quantum world).

The scientific process and perspective in the face of a paradigm shift

Our call to test non-local consciousness theories is not a proposal to discard physicalist theories. There is no question that, as a set of assumptions, materialism has proven to be outstandingly successful in elucidating the nature of physical reality, and it will likely continue to be useful. However, the phenomena we have highlighted here bring some level of doubt to the ability of physicalist theories to explain *everything*, including the nature, origin, and capacities of consciousness. Here we propose that materialism be viewed as a special case of a more comprehensive metaphysic, one that includes consciousness in some fundamental way. This approach is akin to regarding classical physics as a special case, one that describes a limited domain of the physical world. Quantum mechanics, too, is probably a special case because, so far, it is not compatible with relativistic physics. These "modern" physical theories are more comprehensive than classical physics and are special cases.

Promoting the value of more comprehensive models of reality can be challenging. As Max Planck said, "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (Planck, 1950, p. 33). Researchers testing if this statement was true found that, indeed, acceptable scientific models and concepts became more varied after leaders in their field died (Azoulay et al., 2019).

A classic example of shifts in worldviews in science is the case of black holes. Imagine it is 1921, and we asked, "Do black holes exist?" In 1915, Karl Schwarzschild solved Einstein's equations of general relativity for the limited case of a single spherical non-rotating mass. In the process, he discovered the possibility that under extreme gravitational conditions, space could collapse upon itself. Einstein denied that these "black holes" could possibly form. In 1939, he published a paper arguing that a star collapsing would spin faster and faster, eventually spinning at the speed of light with infinite energy, well before the point that it would collapse into a singularity. It was not until the 1960s when Roger Penrose published more detailed models showing how black holes could form, that other physicists considered them viable. A half-century later, astronomers finally observed a black hole (The Event Horizon Telescope Collaboration). In fact, a team of Harvard scientists just released an image of Sagittarius A-star, a black hole at the center of our Milky Way galaxy (McDermott-Murphy, 2022).

We propose that today's understanding of the evidence for non-local consciousness is similar to what was understood about black holes in 1921. A jury of leading scientists in 1921 charged with deciding if black holes existed would have weighed the pros and cons of existing theory and data, they would have consulted with Einstein, and they would have almost certainly decided that black holes could not exist and therefore did not exist. As we know today, they would have been wrong.

Conclusion

Intriguing phenomena are alluding to consciousness being associated with – but not limited by – brain activity. We are in a position similar to those who were studying the possibility of black holes a century ago. Perhaps in 50 years, we will look back on the current transitional period between materialistic and post-materialistic paradigms in science and more clearly understand why we could not have possibly grasped the whole picture.

We can learn from the black hole example to release our desire to prove non-local consciousness and instead remain in a state of curiosity, focusing on methods and improved measures. Even if it were not possible to definitively demonstrate that consciousness is non-local but in the process of determining that, it was discovered that there were non-local aspects of consciousness that we learned more about and controlled to some extent, our world would be radically transformed with the shift in the understanding of our capacities and its practical applications. The systematic scientific study of consciousness is still in its infancy, and thus, we are at the very beginning of understanding the right questions to ask.

This review also calls for humility, open-mindedness, and collaboration in science. Is it possible to remain neutral about the various theories of consciousness? Perhaps physicalist theories will be tested and shown to be relevant in particular situations. Perhaps non-materialist theories will also be tested and shown to be valid in other situations. Could it be that multiple theories of consciousness are tested and found viable? If so, what would that mean about the nature of reality? Can these theories be evaluated for similarities and differences, perhaps combining some and ultimately testing them? Templeton World Charity Foundation Program 'Accelerating Research on Consciousness' has spearheaded such an initiative for physicalist theories. The same could be implemented for non-physicalist theories (Templeton World Charity Foundation, 2022). Is there an interaction between a non-local consciousness interfacing with the physical and/or quantum brain that is persuasively describable? Remaining open and flexible about these possibilities is essential in supporting the birth of new ideas. Remaining humble allows us to review other theories without prejudice.

To further assess the vast number of theories of consciousness, physicalist and non-local, we invite theorists to attempt to make their theories increasingly precise so that abstract terms become quantifiable predictions that can be confirmed or refuted. Furthermore, theorists could attempt to use similar language/terms to improve the clarity regarding the distinctions and commonalities across theories. Criteria could be developed, allowing researchers to easily determine the nature/aspect of consciousness discussed by the theory, the proposed processes that explain how non-local consciousness may interact with physical substrates, and the precise predictions to validate it. Physicalist theories might be closer to validating or invalidating their predictions if the assumption about the nature of consciousness being generated from the brain is correct. However, these predictions may never address the possibility that consciousness is a fundamental property of reality with non-local properties (i.e., they address physical mechanisms but not the nature of consciousness itself).

In conclusion, our reported phenomena of non-local consciousness present intriguing examples that should be addressed when evaluating whether consciousness may be more than an emergent property of brain activity. Despite sophisticated physicalist theories of consciousness dependent on brain function, these examples apparently demonstrate non-local aspects of consciousness, perceiving information in a way that is not limited by our conventional understanding of time and space and that is not dependent on the brain function. Many of these data have been observed with objective measures in the laboratory in a valid and reliable way or collected in the field with impeccable methods and exclusion of fraud. While materialism explains much in our world, it does not explain everything, including these phenomena. Non-materialist theories encompassing consciousness as fundamental and/or non-local may provide a pathway to understanding these phenomena. Perhaps holding the hypothetical assumption that consciousness *is* fundamental and focusing on what we can learn about the mechanism, mediators, moderators, and practical applications of non-local consciousness will reveal novel areas to explore.

Author contributions

HW contributed to the conceptualization, funding acquisition, project administration, and writing – original draft preparation, review, and editing. DR and AD contributed to the conceptualization, funding acquisition, and writing – original draft preparation, review, and editing. CC contributed to the conceptualization and writing – review and editing.

All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Achterberg, J., Cooke, K., Richards, T., Standish, L. J., Kozak, L., and Lake, J. (2005). Evidence for correlations between distant intentionality and brain function in recipients: A functional magnetic resonance imaging analysis. *J. Altern. Complement. Med.* 11, 965–971. doi: 10.1089/acm.2005.11.965

Albantakis, L. (2020). "Integrated information theory," in *Beyond neural correlates of consciousness*, eds A. Kirkeby-Hinrup, J. Mogensen, and M. Overgaard (Abingdon: Routledge).

Albantakis, L., Hintze, A., Koch, C., Adami, C., and Tononi, G. (2014). Evolution of integrated causal structures in animats exposed to environments of increasing complexity. *PLoS Comput. Biol.* 10:e1003966. doi: 10.1371/journal.pcbi.1003966

Aru, J., Bachmann, T., Singer, W., and Melloni, L. (2012). Distilling the neural correlates of consciousness. *Neurosci. Biobehav. Rev.* 36, 737–746. doi: 10.1016/j.neubiorev.2011.12.003

Azoulay, P., Fons-Rosen, C., and Zivin, J. S. G. (2019). Does science advance one funeral at a time? *Ame. Econ. Rev.* 109, 2889–2920. doi: 10.1257/aer.20161574

Baars, B. J. (2005). Global work-space theory of consciousness: Toward a cognitive neuroscience of human experience. *Prog. Brain Res.* 150, 45–53. doi: 10.1016/S0079-6123(05)50004-9

Baars, B. J., Geld, N., and Kozma, R. (2021). Global Workspace Theory (GWT) and prefrontal cortex: Recent developments. *Front. Psychol.* 12:749868. doi: 10.3389/fpsyg.2021.749868

Baptista, J., Derakhshani, M., and Tressoldi, P. E. (2015). "Explicit anomalous cognition: A review of the best evidence in ganzfeld, forced choice, remote viewing and dream studies," in *Parapsychology: A handbook for the 21st century*, eds E. Cardeña, J. Palmer, and D. Marcusson-Clavertz (Jefferson, NC: McFarland & Company, Inc., Publishers), 192–214.

Barrett, L. F. (2016). The theory of constructed emotion: An active inference account of interoception and categorization. *Soc. Cogn. Affect. Neurosci.* nsw154. doi: 10.1093/scan/nsw154

Batthyány, A., and Greyson, B. (2021). Spontaneous remission of dementia before death: Results from a study on paradoxical lucidity. *Psychol. Conscious.* 8, 1–8. doi: 10.1037/cns0000259

Bem, D. J., and Honorton, C. (1994). Does psi exist? Replicable evidence for an anomalous process of information transfer. *Psychol. Bull.* 115, 4–18. doi: 10.1037/0033-2909.115.1.4

Bem, D. J., Tressoldi, P., Rabeyron, T., and Duggan, M. (2015). Feeling the future: A meta-analysis of 90 experiments on the anomalous anticipation of random future events. *F1000Res.* 4:1188. doi: 10.12688/f1000research.7177.2

Bierman, D., and Jolij, J. J. (2020). Dealing with the experimenter effect. *J. Sci. Explor.* 34, 703–709. doi: 10.31275/20201871

Blumenfeld, H., and Taylor, J. (2003). Why do seizures cause loss of consciousness? *Neuroscientist* 9, 301–310. doi: 10.1177/1073858403255624

Bourguignon, E. (1976). *Possession*. Novato,CA: Chandler & Sharp Publishers.

Braud, W., and Schlitz, M. (1983). Psychokinetic influence on electrodermal activity. *J. Parapsychol.* 47, 95–119.

Cardeña, E. (2018). The experimental evidence for parapsychological phenomena: A review. *Am. Psychol.* 73, 663–677. doi: 10.1037/amp0000236

Castro, M., Burrows, R., and Wooffitt, R. (2014). The paranormal is (still) normal: The sociological implications of a survey of paranormal experiences in Great Britain. *Sociol. Res. Online* 19:16. doi: 10.5153/sro.3355

Chalmers, D. J. (1996). *The conscious mind: In search of a fundamental theory*. Oxford: Oxford University Press.

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behav. Brain Sci.* 36, 181–204. doi: 10.1017/S0140525X12000477

Cleeremans, A., Achoui, D., Beauny, A., Keuninckx, L., Martin, J.-R., Muñoz-Moldes, S., et al. (2020). Learning to Be Conscious. *Trends Cogn. Sci.* 24, 112–123. doi: 10.1016/j.tics.2019.11.011

Close, E. R. (2018). *Gimmel, life and consciousness*. Available online at: http://www.erclosetphysics.com/2018/05/gimmel-life-and-consciousness.htmlAD (accessed May 27, 2022).

Cohn, S. A. (1994). A survey on Scottish second sight. *J. Soc. Psych. Res.* 59, 385–400. doi: 10.1001/jamaoncol.2021.6987

Currivan, J. (2017). *The cosmic hologram: In-formation at the center of creation*. New York, NY: Simon and Schuster.

de Graaf, T. A., Hsieh, P.-J., and Sack, A. T. (2012). The "correlates" in neural correlates of consciousness. *Neurosci. Biobehav. Rev.* 36, 191–197. doi: 10.1016/j.neubiorev.2011.05.012

Dehaene, S., Charles, L., King, J.-R., and Marti, S. (2014). Toward a computational theory of conscious processing. *Curr. Opin. Neurobiol.* 25, 76–84.

Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J.-F., Poline, J.-B., et al. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nat. Neurosci.* 4, 752–758. doi: 10.1038/89551

Dehaene, S., Sergent, C., and Changeux, J.-P. (2003). A neuronal network model linking subjective reports and objective physiological data during conscious perception. *Proc. Natl. Acad. Sci. U.S.A.* 100, 8520–8525.

Dossey, L. (1994). Healing and the mind: Is there a dark side? *J. Sci. Explor.* 8, 73–90.

Dunne, B. J., and Jahn, R. G. (2003). Information and uncertainty in remote perception research. *J. Sci. Explor.* 17, 207–241.

Faggin, F. (2021a). "Consciousness Comes First," in *Consciousness unbound: Liberating mind from the tyranny of materialism*, eds E. F. Kelly and P. Marshall (Lanham, MD: Rowman & Littlefield Publishers), 283–322.

Faggin, F. (2021b). *Silicon: From the invention of the microprocessor to the new science of consciousness*. Sea, CA: Waterside Productions.

Fenwick, P., Lovelace, H., and Brayne, S. (2010). Comfort for the dying: Five year retrospective and one year prospective studies of end of life experiences. *Arch. Gerontol. Geriatr.* 51, 173–179.

Friston, K. (2010). The free-energy principle: A unified brain theory? *Nat. Rev. Neurosci.* 11, 127–138. doi: 10.1038/nrn2787

Gershman, S. J. (2019). The generative adversarial brain. *Front. Artif. Intell.* 2:18. doi: 10.3389/frai.2019.00018

Goff, P. (2019). *Galileo's error: Foundations for a new science of consciousness*. New York, NY:: Pantheon Books.

Greeley, A. (1987). Mysticism goes mainstream. *Am. Health* 7, 47–49.

Grossberg, S. (2013a). Adaptive resonance theory. *Scholarpedia* 8:1569. doi: 10.4249/scholarpedia.1569

Grossberg, S. (2013b). Adaptive resonance theory: How a brain learns to consciously attend, learn, and recognize a changing world. *Neural Netw.* 37, 1–47. doi: 10.1016/j.neunet.2012.09.017

Guillemant, P. (2016). *Theory of double causality. Time matters review.* Available online at: http://www.guillemant.net/english/Theory_of_Double_Causality.pdf

Guillemant, P., and Medale, M. (2019). A unique but flexible space–time could challenge multiverse theories. *Ann. Phys.* 409:167907. doi: 10.1016/j.aop.2019.05.005

Hameroff, S. (2021). 'Orch OR' is the most complete, and most easily falsifiable theory of consciousness. *Cogn. Neurosci.* 12, 74–76. doi: 10.1080/17588928.2020.1839037

Hameroff, S., and Penrose, R. (2014). Consciousness in the universe: A review of the 'Orch OR' theory. *Phys. Life Rev.* 11, 39–78. doi: 10.1016/j.plrev.2013.08.002

Haraldsson, E. (1985). Representative national surveys of psychic phenomena: Iceland, Great Britain, Sweden, USA and Gallup's multinational survey. *J. Soc. Psych. Res.* 53, 145–158.

Haraldsson, E. (2011). Psychic experiences a third of a century apart: Two representative surveys in Iceland with an international comparison. *J. Soc. Psych. Res.* 75:76.

Haraldsson, E. (2012). Further facets of Indridi indridason's mediumship, including "transcendental" music, direct speech, xenoglossy and light phenomena. *J. Soc. Psych. Res.* 76, 129–149.

Haraldsson, E., and Houtkooper, J. M. (1991). Psychic experiences in the multinational human values study: Who reports them. *J. Am. Soc. Psych. Res.* 85, 145–165.

Harary, K., and Targ, R. (1985). A new approach to forecasting commodity futures. *Psi Res.* 4, 79–88.

Haun, A., and Tononi, G. (2019). Why does space feel the way it does? Towards a principled account of spatial experience. *Entropy* 21:1160. doi: 10.3390/e21121160

Hebb, D. O., and Penfield, W. (1940). Human behavior after extensive bilateral removal from the frontal lobes. *Arch. Neurol. Psychiatry* 44, 421–438. doi: 10.1001/archneurpsyc.1940.02280080181011

Hoffman, D. D. (2014). The origin of time in conscious agents. *Cosmology* 18, 494–520.

Hoffman, D. D. (2019). *The case against reality: Why evolution hid the truth from our eyes*. New York, NY: W.W. Norton & Company.

Hoffman, D. D., Singh, M., and Prakash, C. (2015). The interface theory of perception. *Psychon Bull. Rev.* 22, 1480–1506. doi: 10.3758/s13423-015-0890-8

Hohwy, J. (2013). *The predictive mind*. Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780199682737.001.0001

Hohwy, J., and Seth, A. (2020). Predictive processing as a systematic basis for identifying the neural correlates of consciousnes. *Psyarxiv*[Preprint]. doi: 10.33735/phimisci.2020.II.64

Honorton, C., Ferrari, D. B., and Hansen, G. (2018). "Meta-analysis of Forced-Choice Precognition Experiments (1935–1987)," in *The star gate archives: Reports of the united states government sponsored psi program, 1972-1995. volume 2: Remote viewing, 1985-1995*, eds E. C. May and S. B. Marwaha (Jefferson, NC: McFarland & Company, Inc., Publishers), 291.

Huang, Y., and Rao, R. P. N. (2011). Predictive coding. *Wiley Interdiscip. Rev. Cogn. Sci.* 2, 580–593. doi: 10.1002/wcs.142

Hudetz, A. G. (2012). General anesthesia and human brain connectivity. *Brain Connect.* 2, 291–302. doi: 10.1089/brain.2012.0107

Hyman, R. (2010). Meta-analysis that conceals more than it reveals: Comment on storm et al. (2010). *Psychol. Bull.* 136, 486–490. doi: 10.1037/a0019676

Kalra, A. P., Hameroff, S., Tuszynski, J., Dogariu, A., Sachin, N., and Gross, P. J. (2020). *Anesthetic gas effects on quantum vibrations in microtubules – Testing the Orch OR theory of consciousness. OSF*. Available online at: https://osf.io/zqnjd/ (accessed May 5, 2022).

Kastrup, B. (2017). Self-transcendence correlates with brain function impairment. *J. Cogn. Neuroethics* 4, 33–42.

Kastrup, B. (2021). "Analytic idealism and psi: How a more teneable metaphysics neutralizes a physicalist taboo," in *Consciousness unbound: Liberating mind from the tyranny of materialism*, eds E. F. Kelly and P. Marshall (Lanham: Rowman & Littlefield Publishers), 257–283.

Kelly, E. W., Greyson, B., and Kelly, E. F. (2007). "Unusual experiences near death and related phenomena," in *Irreducible mind: Toward a psychology for the 21st century*, eds E. F. Kelly, E. W. Kelly, A. Crabtree, A. Gauld, M. Grosso, and B. Greyson (Lanham: Rowman and Littlefield), 367–421.

Keppler, J. (2018). The role of the brain in conscious processes: A new way of looking at the neural correlates of consciousness. *Front. Psychol.* 9:1346. doi: 10.3389/fpsyg.2018.01346

Koch, C. (2018). What is consciousness? *Nature* 557, S8–S12. doi: 10.1038/d41586-018-05097-x

Koch, C., Massimini, M., Boly, M., and Tononi, G. (2016). Neural correlates of consciousness: Progress and problems. *Nat. Rev. Neurosci.* 17, 307–321. doi: 10.1038/nrn.2016.22

Kolodziejzyk, G. (2013). Greg Kolodziejzyk's 13-year associative remote viewing experiment results. *J. Parapsychol.* 76, 349–368.

Lamme, V. A. F. (2006). Towards a true neural stance on consciousness. *Trends Cogn. Sci.* 10, 494–501. doi: 10.1016/j.tics.2006.09.001

Lamme, V. A. F. (2010). How neuroscience will change our view on consciousness. *Cogn. Neurosci.* 1, 204–220. doi: 10.1080/17588921003731586

Lamme, V. A., and Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends Neurosci.* 23, 571–579. doi: 10.1016/s0166-2236(00)01657-x

Lau, H. (2019). Consciousness, metacognition, & perceptual reality monitoring. *PsyArXiv* [Preprint]. doi: 10.31234/osf.io/ckbyf

Lau, H., and Rosenthal, D. (2011). Empirical support for higher-order theories of conscious awareness. *Trends Cogn. Sci.* 15, 365–373. doi: 10.1016/j.tics.2011.05.009

Leopold, D. A., and Logothetis, N. K. (1999). Multistable phenomena: Changing views in perception. *Trends Cogn. Sci.* 3, 254–264. doi: 10.1016/S1364-6613(99)01332-7

Macleod, A. D. S. (2009). Lightening up before death. *Palliat. Support. Care* 7, 513–516. doi: 10.1017/S1478951509990526

Mashour, G. A., Frank, L., Batthyany, A., Kolanowski, A. M., Nahm, M., Schulman-Green, D., et al. (2019). Paradoxical lucidity: A potential paradigm shift for the neurobiology and treatment of severe dementias. *Alzheimers Dement. J. Alzheimers Assoc.* 15, 1107–1114. doi: 10.1016/j.jalz.2019.04.002

Mashour, G. A., Roelfsema, P., Changeux, J.-P., and Dehaene, S. (2020). Conscious processing and the global neuronal workspace hypothesis. *Neuron* 105, 776–798. doi: 10.1016/j.neuron.2020.01.026

May, E. C., and Marwaha, S. B. (2018). *The star gate archives: reports of the united states government sponsored psi program, 1972-1995*, Vol. 1. Jefferson, NC: McFarland & Company, Inc., Publishers.

McClenon, J. (1993). Surveys of anomalous experience in Chinese. Japanese, and American samples. *Sociol. Relig.* 54, 295–302.

McCraty, R., Atkinson, M., and Bradley, R. T. (2004). Electrophysiological evidence of intuition: Part 1. The surprising role of the heart. *J. Altern. Complement. Med.* 10, 133–143. doi: 10.1089/107555304322849057

McDermott-Murphy, C. (2022). *The dawn of a new era in astronomy. Harvard Gazette*. Available online at: https://news.harvard.edu/gazette/story/2022/05/the-dawn-of-a-new-era-in-astronomy/

Mcmoneagle, J. W., and May, E. C. (2004). "The possible role of intention, attention and expectation in remote viewing," in *Proceedings of Presented Papers. The Parapsychological Association 47th Annual Convention*, (Vienna: Vienna University).

Milton, J. (1997). Meta-analysis of free-response ESP studies without altered states of consciousness. *J. Parapsychol.* 61, 279–319.

Mossbridge, J., and Radin, D. (2018). Precognition as a form of prospection: A review of the evidence. *Psychol. Conscious.* 5:78.

Mossbridge, J., Tressoldi, P., and Utts, J. (2012). Predictive physiological anticipation preceding seemingly unpredictable stimuli: A meta-analysis. *Front. Psychol.* 3:390. doi: 10.3389/fpsyg.2012.00390

Mossbridge, J., Tressoldi, P., Utts, J., Ives, J. A., Radin, D., and Jonas, W. B. (2014). Predicting the unpredictable: Critical analysis and practical implications of predictive anticipatory activity. *Front. Hum. Neurosci.* 8:146. doi: 10.3389/fnhum.2014.00146

Mumford, M., Rose, A., and Goslin, D. (1995). *An evaluation of remote viewing: Research and applications*. Arlington: American Institutes for Research.

Nahm, M., and Greyson, B. (2009). Terminal lucidity in patients with chronic schizophrenia and dementia: A survey of the literature. *J. Nerv. Ment. Dis.* 197, 942–944. doi: 10.1097/NMD.0b013e3181c22583

Nahm, M., Greyson, B., Kelly, E. W., and Haraldsson, E. (2012). Terminal lucidity: A review and a case collection. *Arch. Gerontol. Geriatr.* 55, 138–142. doi: 10.1016/j.archger.2011.06.031

Neppe, V. M., and Close, E. R. (2015). Refuting atomic materialism. *IQNexus* 11, 1074–1083.

Neppe, V. M., and Close, E. R. (2020). The Neppe-Close triadic dimensional vortical paradigm: An invited summary. *Int. J. Phys. Res. Appl.* 3, 001–004. doi: 10.29328/journal.ijpra.1001018

Oizumi, M., Albantakis, L., and Tononi, G. (2014). From the phenomenology to the mechanisms of consciousness: Integrated information theory 3.0. *PLoS Comput. Biol.* 10:e1003588. doi: 10.1371/journal.pcbi.1003588

Palmer, J. (1979). A community mail survey of psychic experiences. *J. Am. Soc. Psych. Res.* 73, 221–251.

Palmer, J., and Millar, B. (2015). "Experimenter effects in parapsychological research," in *Parapsychology: A handbook for the 21st century*, eds E. Cardeña, J. Palmer, and D. Marcusson-Clavertz (Jefferson, NC: McFarland & Company, Inc., Publishers), 293–300.

Planck, M. (1950). in *Scientific autobiography and other papers*, ed. F. Gaynor (London: Williams & Northgate).

Radin, D. I. (1997). Unconscious perception of future emotions: An experiment in presentiment. *J. Sci. Explor.* 11, 163–180.

Radin, D. I., Stone, J., Levine, E., Eskandarnejad, S., Schlitz, M., Kozak, L., et al. (2008). Compassionate intention as a therapeutic intervention by partners of cancer patients: Effects of distant intention on the patients' autonomic nervous system. *Explore J. Sci. Heal.* 4, 235–243. doi: 10.1016/j.explore.2008.04.002

Radin, D. I., Vieten, C., Michel, L., and Delorme, A. (2011). Electrocortical activity prior to unpredictable stimuli in meditators and non-meditators. *Explore* 7, 286–299. doi: 10.1016/j.explore.2011.06.004

Radin, D., and Borges, A. (2009). Intuition through time: What does the seer see? *Explore* 5, 200–211. doi: 10.1016/j.explore.2009.04.002

Radin, D., and Lobach, E. (2007). Toward understanding the placebo effect: Investigating a possible retrocausal factor. *J. Altern. Complement. Med.* 13, 733–739. doi: 10.1089/acm.2006.6243

Radin, D., and Pierce, A. (2015). "Psi and Psychophysiology," in *Parapsychology: A handbook for the 21st century*, ed. E. Cardena (Jefferson, NC: McFarland & Company, Inc., Publishers).

Rao, R. P. N., and Ballard, D. H. (1999). Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nat. Neurosci.* 2, 79–87. doi: 10.1038/4580

Reardon, S. (2019). *'Outlandish' competition seeks the brain's source of consciousness*. Available online at: https://www.science.org/content/article/outlandish-competition-seeks-brain-s-source-consciousness (accessed May 16, 2022).

Richards, T. L., Kozak, L., Johnson, L. C., and Standish, L. J. (2005). Replicable functional magnetic resonance imaging. Evidence of correlated brain signals between physically and sensory isolated subjects. *J. Altern. Complement. Med.* 11, 955–963. doi: 10.1089/acm.2005.11.955

Ross, C. A., and Joshi, S. (1992). Paranormal experiences in the general population. *J. Nerv. Ment. Dis.* 180, 357–361.

Saxe, J. G. (2016). *The blind men and the elephant*. Hong Kong: Enrich Spot Limited.

Schlitz, M., Wiseman, R., Watt, C., and Radin, D. (2006). Of two minds: Sceptic-proponent collaboration within parapsychology. *Br. J. Psychol.* 97(Pt 3), 313–322. doi: 10.1348/000712605X80704

Schmidt, S. (2012). Can we help just by good intentions? A meta-analysis of experiments on distant intention effects. *J. Altern. Complement. Med.* 18, 529–533. doi: 10.1089/acm.2011.0321

Schmidt, S. (2015). "Experimental research on distant intention phenomena," in *Parapsychology: A handbook for the 21st century*, eds E. Cardeña, J. Palmer, and D. Marcusson-Clavertz (Jefferson, NC: McFarland & Company, Inc., Publishers), 244–257. doi: 10.1016/j.explore.2015.10.001

Schmidt, S., Schneider, R., Utts, J., and Walach, H. (2004). Distant intentionality and the feeling of being stared at: Two meta-analyses. *Br. J. Psychol.* 95(Pt 2), 235–247. doi: 10.1348/000712604773952449

Schooler, J. (2014). "Bridging the objective/subjective divide: Towards a meta-perspective of science and experience," in *Open MIND*, (Frankfurt: Frankfurt am Main: MIND Group).

Schwartz, S. A. (2005). *The secret vaults of time: Psychic archaeology and the quest for man's beginnings*, Vol. 12. Newburyport, MA: Hampton Roads Publishing.

Schwartz, S. A. (2019). The location and reconstruction of a byzantine structure in marea, egypt, including a comparison of electronic remote sensing and remote viewing. *J. Sci. Explor.* 33, 451–480.

Selimbeyoglu, A., and Parvizi, J. (2010). Electrical stimulation of the human brain: Perceptual and behavioral phenomena reported in the old and new literature. *Front. Hum. Neurosci.* 4:46. doi: 10.3389/fnhum.2010.00046

Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends Cogn. Sci.* 17, 565–573. doi: 10.1016/j.tics.2013.09.007

Seth, A. K., and Bayne, T. (2022). Theories of consciousness. *Nat. Rev. Neurosci.* 23, 439–452. doi: 10.1038/s41583-022-00587-4

Shapiro, K. L., Raymond, J. E., and Arnell, K. M. (1997). The attentional blink. *Trends Cogn. Sci.* 1, 291–296. doi: 10.1016/S1364-6613(97)01094-2

Simons, D. J., and Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception* 28, 1059–1074. doi: 10.1068/p281059

Smith, C. C., Laham, D., and Moddel, J. (2014). Stock market prediction using associative remote viewing by inexperienced remote viewers. *J. Sci. Explor.* 28, 7–16.

Standish, L. J., Johnson, L. C., Kozak, L., and Richards, T. (2003). Evidence of correlated functional magnetic resonance imaging signals between distant human brains. *Altern. Ther.* 9, 122–125.

Standish, L. J., Kozak, L., Johnson, L. C., and Richards, T. (2004). Electroencephalographic evidence of correlated event-related signals between the brains of spatially and sensory isolated human subjects. *J. Altern. Complement. Med.* 10, 307–314. doi: 10.1089/107555304323062293

Steriade, M., Timofeev, I., and Grenier, F. (2001). Natural waking and sleep states: A view from inside neocortical neurons. *J. Neurophysiol.* 85, 1969–1985. doi: 10.1152/jn.2001.85.5.1969

Stevenson, I., and Pasricha, S. (1979). A case of secondary personality with xenoglossy. *Am. J. Psychiatry* 136, 1591–1592. doi: 10.1176/ajp.136.12.1591

Stevenson, I., and Pasricha, S. (1980). A preliminary report on an unusual case of the reincarnation type with xenoglossy. *J. Am. Soc. Psych. Res.* 74, 331–348.

Storm, L., and Tressoldi, P. (2020). Meta-analysis of free-response studies 2009-2018: Assessing the noise-reduction model ten years on. *J. Soc. Psych. Res.* 84, 193–219.

Storm, L., Tressoldi, P. E., and Di Risio, L. (2010). Meta-analysis of free-response studies, 1992-2008: Assessing the noise reduction model in parapsychology. *Psychol. Bull.* 136, 471–485. doi: 10.1037/a0019457

Storm, L., Tressoldi, P. E., and Di Risio, L. (2012). Meta-analysis of ESP studies, 1987-2010: Assessing the success of the forced-choice design in parapsychology. *J. Parapsychol.* 76, 243–273.

Templeton World Charity Foundation. (2022). *Accelerating research on consciousness. Templeton world charity foundation*. Available online at: https://www.templetonworldcharity.org/our-priorities/accelerating-research-consciousness (accessed May 19, 2022).

Tononi, G. (2015). Integrated information theory. *Scholarpedia* 10:4164. doi: 10.4249/scholarpedia.4164

Tononi, G., Boly, M., Massimini, M., and Koch, C. (2016). Integrated information theory: From consciousness to its physical substrate. *Nat. Rev. Neurosci.* 17, 450–461. doi: 10.1038/nrn.2016.44

Treffert, D. A. (2009). The savant syndrome: An extraordinary condition. A synopsis: Past, present, future. *Philos. Trans R. Soc. Lond. B. Biol. Sci.* 364, 1351–1357. doi: 10.1098/rstb.2008.0326

Tressoldi, P., Martinelli, M., Zaccaria, E., and Massaccesi, S. (2009). Implicit intuition: How heart rate can contribute to predict future events. *J. Soc. Psych. Res.* 73, 1–16.

Utts, J. (2016). Appreciating Statistics. *J. Am. Stat. Assoc.* 111, 1373–1380. doi: 10.1080/01621459.2016.1250592

Vandersande, J. W. (2008). *Life after death: Some of the best evidence*. Denver: Outskirts Press, Inc.

VanRullen, R., and Kanai, R. (2021). Deep learning and the Global Workspace Theory. *Trends Neurosci.* 44, 692–704. doi: 10.1016/j.tins.2021.04.005

Wahbeh, H., Radin, D., Mossbridge, J., Vieten, C., and Delorme, A. (2018). Exceptional experiences reported by scientists and engineers. *Explore* 14, 329–341. doi: 10.1016/j.explore.2018.05.002

Watt, C., Wiseman, R., and Schlitz, M. (2002). Tacit information in remote staring research: The Wiseman-Schlitz interviews. *Paranormal Rev.* 24, 18–25.

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How much consciousness is there in complexity?

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The notion of complexity currently receives significant attention in neuroscience, mainly through the popularity of the Integrated Information Theory (IIT). It has proven successful in research centred on discriminating states of consciousness, while little theoretical and experimental effort was directed toward studying the content. In this paper, we argue that exploring the relationship between complexity and conscious content is necessary to understand the importance of information-theoretic measures for consciousness research properly. We outline how content could be experimentally operationalised and how rudimental testable hypotheses can be formulated without requiring IIT formalisms. This approach would not only allow for a better understanding of aspects of consciousness captured by complexity but could also facilitate comparison efforts for theories of consciousness.

KEYWORDS
consciousness, complexity, neural correlates of consciousness, state, content

Introduction

The notion of complexity currently receives a significant amount of attention in neuroscience. It is frequently used as a shorthand for applying the information-theoretic approach to study the relation between the mind and the brain. Although problematic (Ladyman et al., 2013), this could be seen as an extrapolation of the complexity of the brain as a biological structure to the mind. It could also be an inevitable consequence of the dominance of the computer metaphor in cognitive neuroscience (Gigerenzer and Goldstein, 1996), where the mind is conceptualised as an information processing system. Similarly, in consciousness science approaches based on complexity were first popularised by the work of Tononi and Edelman (1998) and later evolved into Integrated Information Theory (IIT; Oizumi et al., 2014), which is considered presently one of the most influential theories available. A large part of this prominence can be attributed to the successful application of complexity measures to the discrimination of states of consciousness (Sarasso et al., 2021), supporting the general theoretical claims of the theory.

Complexity became so ubiquitous in the literature about IIT that it is frequently treated synonymously with applying the theoretical principles of this approach. This limits the discussion on the usefulness of information theory in understanding the neural basis of consciousness to the ontological frame of IIT. Consequently, critical assessments of IIT tend to dismiss the usefulness and importance of complexity measures based on theoretical problems that IIT bears in their view (for a recent example, see: Merker et al., 2022; with responses). The impracticality of this situation has been recently recognised by Mediano et al. (2022); however, they advocate only on behalf of a "weak version" of IIT with relaxed ontological claims, focused on a more thorough assessment of the behaviour of measures of information dynamics to different aspects of consciousness. In this article, we call for a more radical decoupling of the notion of complexity from IIT, allowing for a broader assessment of its usefulness irrespective of the theoretical approach. Furthermore, we argue that every theory employing complexity measures must address its relation to conscious content to be treated as a proper theory of consciousness.

Paradox of phenomenology in integrated information theory

The proponents of IIT describe it as derived solely from the phenomenology of conscious experience (Tononi et al., 2016). They argue that philosophical analysis of the structure of phenomenal experience, translated into physical terms, creates an identity relation where all of the subjectivity is captured through the properties of a conceptual structure. Moreover, this precise translation based on mathematical notations should allow, in principle, scientific inquiry of said structure. This theoretical assumption equates investigation of its properties to exploring subjective experience, legitimising the use of numerical methods as indicators of the presence of consciousness as such. Since this structure is defined in terms of cause-effect power as a multiway interaction of simple elements (Oizumi et al., 2014), it can be assessed, or at least approximated, by measures of complexity (Arsiwalla and Verschure, 2018). IIT interprets these measurements as describing the quantitative aspect or consciousness (Tononi and Koch, 2015), which in empirical studies is equated to the state of consciousness (Sarasso et al., 2021), spanning from full wakefulness to deep sleep, anaesthesia or coma.

Proponents of IIT point to this line of reasoning as an argument in favour of the validity of the whole theory. They start from the core of consciousness, namely phenomenal experience. Through logical and mathematical analysis, they arrive at a conceptual model, parametrisation of which allows measuring consciousness in real-world data. It seems, however, that this completeness is only illusory since the notion of consciousness they started with differs from the one identified at the end. IIT begins with formulating five axioms about the phenomenal experience (Oizumi et al., 2014) that refer only to its formal properties. Importantly, these axioms seem to operate in an all-or-nothing manner, being strictly necessary for the subjective experience to arise. On the other hand, what is typically assessed in studies employing complexity measures is only the state of consciousness (Sarasso et al., 2021), often interpreted rather as a general level of wakefulness. It is typically thought of as a continuum with different levels (Bayne et al., 2016), but it is not derivable from axioms proposed by IIT as it does not refer directly to any phenomenal properties. Interestingly, neither the formal analyses nor the empirical studies include the notion of conscious content, which is the central focus of phenomenology and a necessary element for ascribing consciousness to a person.

There is no denying that measures derived from information theory have proven to be a robust indicator of the level of consciousness in clinical and non-clinical conditions (Sarasso et al., 2021), also in comparison with other approaches (Nilsen et al., 2020). Though these conditions are characterised by disparate differences between consciousness and unconsciousness, with accompanying profound physiological changes, proponents of IIT tend to treat this as evidence confirming the theory's assumptions. However, with the lack of studies tying derived measures to phenomenal qualities of conscious content, opponents of this approach can always point to the relation between the state and complexity as an argument against identifying it with actual consciousness. They could argue that this observed relation indicates that complexity measures capture only the necessary but not sufficient properties for conscious awareness. Merker et al. (2022) name it "efficient information processing" and suggest it might be a general organisational property that by design or evolution can be found in many complex systems, most of which can hardly be described as conscious or even alive in any meaningful way.

Interestingly, referring to axioms as a direct connection of the theory to phenomenology could also be treated as necessary but insufficient. Since the properties of the abstract causal structure are based on axioms derived from structural aspects of experience and do not describe the phenomenal content itself, they too can be interpreted as necessary but not sufficient for consciousness. What is more problematic, the way axioms are formulated prevents any form of experimental manipulation that could prove their sufficiency. Paradoxically, distilling the phenomenality of conscious experience in IIT to its fundamental properties might have led to axioms that are not specific enough to constitute the conscious subjective experience. Therefore, it seems crucial for IIT or any approach based on complexity to explore the relationship between those measures and conscious content experimentally, as this is the only way to prove that it captures the neuronal basis of consciousness and not only something like efficient information processing.

Complexity and conscious experience

One of the biggest appeals of IIT is its promise to capture in a single mechanism both dimensions typically used to describe consciousness, namely the state and content (Tononi and Koch, 2015). The state is understood quantitatively as the degree of integration, and a special measure Φ is designed to represent it. On the other hand, the content is described as the shape of this conceptual structure, but currently, IIT does not provide any way of quantifying it. Some researchers point to the rate of change of conscious experience in time as its measurable aspect and connect it to the concept of differentiation (Sarasso et al., 2021). This seems surprising as most theoretical foundations of IIT are built upon "phenomenological atoms" that constitute the conceptual structure in its core and are organised according to proposed axioms. This can be seen in graphical representations accompanying theoretical analyses, where each structural element is a distinguishable phenomenal quality (Tononi et al., 2016) matched to a particular set of neurons. In newer works, in which proponents of IIT attempt to formally describe the experience of space (Haun and Tononi, 2019; Ellia et al., 2021), they seem to go even further, dividing space into small parts (akin to pixels in an LCD screen) that can be related structurally and functionally to the organisation of neurons in the cortex. Conscious experience in IIT has an inherent quantitative granularity built in that has not been yet translated into testable predictions, although these space-related papers seem like a groundwork for future experimental studies.

This situation is understandable since the focus of IIT is on the mechanism of integration, where the whole conceptual structure representing subjective experience exceeds the contribution of its parts and constitutes consciousness as such. This emergent behaviour being a central part of the theory is probably one of the reasons some researchers think that a weaker version, not tied to particular ontological claims, would allow for more broad research (Mediano et al., 2022), benefiting in the end, the IIT itself. We agree that loosening theoretical ties between IIT and measures based on information theory would accelerate the assessment of their connection to consciousness. However, we think that a more radical decoupling is necessary to make the best use of the research resources available now. In the rest of the paper, we want to propose how testable predictions about the conscious experience can be formulated that take advantage of the robustness of complexity measures and are also based on fundamental phenomenological properties but avoid strong ontological claims of any particular theory through relying only on assumptions present in the general paradigm of cognitive neuroscience that overarches most of the contemporary theories of consciousness. This common denominator of treating the brain and mind as information processing systems lines itself well with information-theoretic measures, allowing for a common ground on which different theories could be compared and evaluated.

Complexity and conscious content

In our view, the central phenomenological insight connected to the notion of complexity is the richness of conscious experience (Block, 1995). In the most general sense, it refers to a plethora of content populating subjective experience that is clearly distinguishable and has various qualitative properties. The extent of this richness is still being debated (Kouider et al., 2010; Block, 2011), but it is hard to deny that during normal wakefulness, a person is simultaneously consciously aware of multiple things, e.g., objects present in their field of view. The second insight concerns the unity of conscious experience, but only to the extent that all of conscious content is combined and arranged in one coherent entity. Crucially, this entity feels complete and fully occupying the "space in our mind," yet trivial examples prove that we can meaningfully describe it in quantitative terms, e.g., closing one's eyes or turning off the radio lowers the number of things one is conscious of.

Moreover, content not only coexists in conscious experience, but also all elements are in relation to each other, creating a complex arrangement that is more than just the sum of its parts. This, of course, echoes the views of the Gestalt tradition (Wertheimer, 1938) but also is in line with the IIT as it comes to richness (Haun et al., 2017) as well as unity, which is one of the axioms (Oizumi et al., 2014). Assuming every experienced content and its qualities have some distinct neural basis, we can provisionally postulate that interactions between contents of consciousness should be reflected by some neural processes. Therefore, richness of conscious experience would have to correlate with some aspects of the complexity of neuronal interactions (e.g., local or global dynamics, non-linear causal influence, or their interaction in a form of hierarchy of complexity).

Following this line of thought, we can formulate testable hypotheses based on the assumption that some aspect of phenomenal experience, namely conscious content, can be quantified and experimentally manipulated to search for brain activity correlated with those subjective changes. Most intuitively, this quantification of content can be understood in a straightforward additive sense, e.g., there is more conscious content when a participant is presented with two objects on the screen instead of only one. The rationale would point to the engagement of more sensory neurons for longer periods, creating a more complex interaction between them and other cortical regions. Similarly, this would also include variation in the intensity of physical stimulation, e.g., brightness or loudness, that results in changes in the experience. This psychophysical approach would allow for fine-grained control over participants' subjective experience, enabling the researchers to search for a measure that would generalise over different qualities and modalities. Crucially, comparisons would be made when subjects are fully awake, ensuring that variability in the state of consciousness is minimised.

Alternatively, one can point to multisensory integration as another way for one's subjective experience to be richer. For example, presenting a movie snippet with synced or misaligned video and audio tracks can be interpreted as addition of perceptual but not physical quality that makes the synced material richer for the participant. This could also be extrapolated on concepts like temporal integration, where the proper order of stimulation, for example a sequence of scenes in a play, allows for a more informationally rich experience. Treating this as an experience contextualised in time, we can also speculate that a similar effect could be observed in the spatial domain. The obvious examples would include laws of perception proposed by the Gestalt school (Wertheimer, 1938) or visual illusions, where specific placement of elements generates more perceptual experience than is present in physical stimulation alone, e.g., Kanizsa triangles (Kanizsa, 1987). Similarly to the psychophysical manipulation mentioned earlier, the state of consciousness is kept constant, but here also the physical stimulation is the same. Despite that, one of the conditions seems to have more qualities than the other.

Experimental support for this line of reasoning already exists. Some of the studies following these principles were conducted by the proponents of IIT themselves. A paper by Boly et al. (2015) assessed the complexity of brain activity recorded with fMRI in response to a short movie, the same movie but with parts in random order, or a static TV noise. They reported an increased level of complexity, as measured by Lempel-Ziv compressibility, from the noise condition through scrambled to the movie in the proper sequence. Importantly, in the general sense, participants maintained the same level of consciousness throughout the whole experiment, so it is reasonable to assign the effects to changes in the content. Interestingly, it seems that not only do we observe an increase in complexity through adding the number of objects (no discernible objects in noise versus movie frame full of content), but also through the introduction of meaning stemming from watching the movie in proper sequence.

There is also a handful of similar effects reported for speech perception (Borges et al., 2018), music production and reception (Dolan et al., 2018), tracking meaningfulness of images (Mensen et al., 2017) and video clips (Mensen et al., 2018), or bistable perception (Canales-Johnson et al., 2020). However, some studies did not find significant differences in similar paradigms (Bola et al., 2018). Sparsity of experimental evidence, mostly small sample sizes, and vastly different paradigms used, indicate a striking disproportion in the amount of attention devoted to studying content compared to states of consciousness. This might result from differences in the magnitude of effects, making it significantly more challenging to show the relation between complexity and conscious content systematically. Despite that, if information-based approaches want to make a compelling case about the mechanism of consciousness, they need to reliably demonstrate how variation in content is accompanied by changes observed through measures of complexity.

We are aware that readers of this article might find the parallel between richness of phenomenal experience and complexity of neuronal interactions as superficial and naïve, a case of mistaken identity, similarly to the critique IIT is facing (Merker et al., 2022). However, we are convinced that consciousness science can only benefit from systematic experimental research that expands beyond the narrow definition of conscious content as isolated objects presented briefly on a monitor's screen. Although simplistic, the proposed approach introduces a principled way in which subjective experience can be experimentally manipulated with more naturalistic, complex, meaningful stimulation. Combining it with complexity measures, currently the most robust tools for detecting conscious activity (Nilsen et al., 2020), gives us a set of testable predictions that even if proven wrong, will expand our understanding of the relation between consciousness and the brain activity.

It is essential to acknowledge that although our approach is deliberately broad enough not to be bound by a conceptual framework of a particular theory, it is still rooted in a research paradigm that seeks for neuronal activity to explain consciousness. While being the most widespread approach among consciousness research community, there are other options available (e.g., Dennett, 1993; Frankish, 2016; Schurger and Graziano, 2022), where phenomenality is denied importance. Some researchers (Rahimian, 2022) argue for their importance as only a radical shift in our conceptualisation of consciousness of a similar kind could move science forward. Our proposition is not aimed at improving the existing frameworks to exceed the limitations of their paradigm. We rather hope for pushing the available methods and theories to their logical limit and hopefully introducing more "points of contact" for the theories to be compared and evaluated. Therefore it must function in the general frame of the paradigm and can be subjected to the same criticism that theories it shares the assumptions with.

Moving forward

There is no denying that complexity captures an essential aspect of brain activity closely related to consciousness. It reliably dissociates levels of wakefulness and shows some promise to quantify the "amount" of phenomenal experience people have. There are, however, many unknowns related to proper ways of calculating the measures of complexity, decisions about the spatial and temporal scale they should be applied to, picking the optimum level of neural hierarchy to assess, or properly defining the conditions that should be contrasted (Sarasso et al., 2021). In our view, progress in these areas is hampered by the connection of the concept of complexity to only one specific theory and treating the results acquired with it as a confirmation of the theoretical assumptions that IIT is founded on. Its critics frequently point to research arguing that similar results could be obtained by many different architectures and systems (Doerig et al., 2019), but similarly treat it only as an argument against IIT and not as the authors intended—a challenge to a whole research program shared by many theories. While many researchers are not convinced that a new paradigm is necessary, there are still new directions we can take to make current efforts more robust and valuable in understanding consciousness.

The most obvious first step would be to systematically explore the relationship between measures of complexity and variability of states and contents of consciousness in broad spectrum of experimental data. Importantly, explicit manipulation of the conscious content is necessary to make any claims about capturing the phenomenal aspect of the experience. This could be realised in several ways, e.g., utilising resting-state paradigms where participants are passively exposed to stimulation on different levels of complexity (Koculak and Wierzchoń, 2022). This would allow for selectively manipulating and comparing the amount of information introduced in one modality and introducing conditions with increasing multimodal complexity. Additionally, using more naturalistic stimuli that imitate real-world experience should make the differences between these conditions more pronounced than artificially generated distortions.

Another option would be tapping into the existing plethora of experimental data, where different aspects of the conscious experience were manipulated and analysed in the context of various theories of consciousness (Yaron et al., 2022). Assuming complexity tracks crucial aspects related to conscious processing, it should be able to discern conscious perception from the unconscious, e.g., in an experiment manipulating awareness of backward masked visual stimuli. Mensen et al. (2017) do it for a novel paradigm, but there is no principled reason why similar analyses could not be done on other already published data. This would have the added benefit of the possibility of comparing how complexity analysis relates to methods like ERPs in capturing changes in consciousness. Collecting a significant amount of such comparisons should highlight aspects where methods agree and disagree, potentially guiding new research paradigms that would allow for a more rigorous comparison of theories (Del Pin et al., 2021; Melloni et al., 2021).

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MK drafted the initial version. Both authors revised the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Arsiwalla, X. D., and Verschure, P. (2018). Measuring the complexity of consciousness. *Front. Neurosci.* 12:424. doi: 10.3389/fnins.2018.00424

Bayne, T., Hohwy, J., and Owen, A. M. (2016). Are there levels of consciousness? *Trends Cogn. Sci.* 20, 405–413. doi: 10/f8pc7t

Block, N. (1995). On a confusion about a function of consciousness. *Behav. Brain Sci.* 18, 227–247. doi: 10.1017/S0140525X00038188

Block, N. (2011). Perceptual consciousness overflows cognitive access. *Trends Cogn. Sci.* 15, 567–575. doi: 10/dvxdzq

Bola, M., Orłowski, P., Baranowska, K., Schartner, M., and Marchewka, A. (2018). Informativeness of auditory stimuli does not affect EEG signal diversity. *Front. Psychol.* 9:1820. doi: 10.3389/fpsyg.2018.01820

Boly, M., Sasai, S., Gosseries, O., Oizumi, M., Casali, A., Massimini, M., et al. (2015). Stimulus set meaningfulness and neurophysiological differentiation: A functional magnetic resonance imaging study. *PLoS One* 10:e0125337. doi: 10.1371/journal.pone.0125337

Borges, A. F. T., Giraud, A.-L., Mansvelder, H. D., and Linkenkaer-Hansen, K. (2018). Scale-free amplitude modulation of neuronal oscillations tracks comprehension of accelerated speech. *J. Neurosci.* 38, 710–722. doi: 10.1523/JNEUROSCI.1515-17.2017

Canales-Johnson, A., Billig, A. J., Olivares, F., Gonzalez, A., Garcia, M., del, C., et al. (2020). Dissociable neural information dynamics of perceptual integration and differentiation during bistable perception. *Cereb. Cortex* 30, 4563–4580. doi: 10.1093/cercor/bhaa058

Del Pin, S. H., Skóra, Z., Sandberg, K., Overgaard, M., and Wierzchoń, M. (2021). Comparing theories of consciousness: Why it matters and how to do it. *Neurosci. Conscious.* 2021:niab019. doi: 10.1093/nc/niab019

Dennett, D. C. (1993). *Consciousness explained*. London: Penguin.

Doerig, A., Schurger, A., Hess, K., and Herzog, M. H. (2019). The unfolding argument: Why IIT and other causal structure theories cannot explain consciousness. *Consciousness Cogn.* 72, 49–59. doi: 10.1016/j.concog.2019.04.002

Dolan, D., Jensen, H. J., Mediano, P. A. M., Molina-Solana, M., Rajpal, H., Rosas, F., et al. (2018). The Improvisational state of mind: A multidisciplinary study of an improvisatory approach to classical music repertoire performance. *Front. Psychol.* 9:1341. doi: 10.3389/fpsyg.2018.01341

Ellia, F., Hendren, J., Grasso, M., Kozma, C., Mindt, G. P., Lang, J. M., et al. (2021). Consciousness and the fallacy of misplaced objectivity. *Neurosci. Conscious.* 2021:niab032. doi: 10.1093/nc/niab032

Frankish, K. (2016). Illusionism as a theory of consciousness. *J. Conscious. Stud.* 23, 11–39.

Gigerenzer, G., and Goldstein, D. G. (1996). Mind as computer: Birth of a metaphor. *Creat. Res. J.* 9, 131–144. doi: 10.1080/10400419.1996.9651168

Haun, A., and Tononi, G. (2019). Why does space feel the way it does? Towards a Principled Account of Spatial Experience. *Entropy* 21:1160. doi: 10.3390/e21121160

Haun, A., Tononi, G., Koch, C., and Tsuchiya, N. (2017). Are we underestimating the richness of visual experience? *Neurosci. Conscious.* 2017:niw023. doi: 10/ghn32m

Kanizsa, G. (1987). "Quasi-perceptual margins in homogeneously stimulated fields," in *The perception of illusory contours*, eds S. Petry and G. E. Meyer (Berlin: Springer), 40–49. doi: 10.1007/978-1-4612-4760-9_4

Koculak, M., and Wierzchoń, M. (2022). Consciousness science needs some rest: How to use resting-state paradigm to improve theories and measures of consciousness. *Front. Neurosci.* 16:836758. doi: 10.3389/fnins.2022.836758

Kouider, S., de Gardelle, V., Sackur, J., and Dupoux, E. (2010). How rich is consciousness? The partial awareness hypothesis. *Trends Cogn. Sci.* 14, 301–307. doi: 10/cfw3zz

Ladyman, J., Lambert, J., and Wiesner, K. (2013). What is a complex system? *Eur. J. Philos. Sci.* 3, 33–67. doi: 10.1007/s13194-012-0056-8

Mediano, P. A. M., Rosas, F. E., Bor, D., Seth, A. K., and Barrett, A. B. (2022). The strength of weak integrated information theory. *Trends Cogn. Sci.* 26, 646–655. doi: 10.1016/j.tics.2022.04.008

Melloni, L., Mudrik, L., Pitts, M., and Koch, C. (2021). Making the hard problem of consciousness easier. *Science* 372, 911–912. doi: 10.1126/science.abj3259

Mensen, A., Marshall, W., Sasai, S., and Tononi, G. (2018). Differentiation analysis of continuous electroencephalographic activity triggered by video clip contents. *J. Cogn. Neurosci.* 30, 1108–1118. doi: 10.1162/jocn_a_01278

Mensen, A., Marshall, W., and Tononi, G. (2017). EEG differentiation analysis and stimulus set meaningfulness. *Front. Psychol.* 8:1748. doi: 10/gb4d4c

Merker, B., Williford, K., and Rudrauf, D. (2022). The integrated information theory of consciousness: A case of mistaken identity. *Behav. Brain Sci.* 45:e41. doi: 10.1017/S0140525X21000881

Nilsen, A. S., Juel, B., Thürer, B., and Storm, J. F. (2020). Proposed EEG measures of consciousness: A systematic, comparative review. *PsyArXiv*[Preprint] doi: 10.31234/osf.io/sjm4a

Oizumi, M., Albantakis, L., and Tononi, G. (2014). From the phenomenology to the mechanisms of consciousness: Integrated information theory 3.0. *PLoS Comput. Biol.* 10:e1003588. doi: 10/sqz

Rahimian, S. (2022). The myth of when and where: How false assumptions still haunt theories of consciousness. *Conscious. Cogn.* 97:103246. doi: 10.1016/j.concog.2021.103246

Sarasso, S., Casali, A. G., Casarotto, S., Rosanova, M., Sinigaglia, C., and Massimini, M. (2021). Consciousness and complexity: A consilience of evidence. *Neurosci. Conscious.* niab023. doi: 10.1093/nc/niab023

Schurger, A., and Graziano, M. (2022). Consciousness explained or described? *Neurosci. Conscious.* 2022:niac001. doi: 10.1093/nc/niac001

Tononi, G., Boly, M., Massimini, M., and Koch, C. (2016). Integrated information theory: From consciousness to its physical substrate. *Nat. Rev. Neurosci.* 17, 450–461. doi: 10/f8rbxc

Tononi, G., and Edelman, G. M. (1998). Consciousness and Complexity. *Science* 282, 1846–1851. doi: 10.1126/science.282.5395.1846

Tononi, G., and Koch, C. (2015). Consciousness: Here, there and everywhere? *Philos. Trans. R. Soc. B Biol. Sci.* 370:20140167. doi: 10.1098/rstb.2014.0167

Wertheimer, M. (1938). "Gestalt theory," in *A source book of gestalt psychology*, ed. W. D. Ellis (London: Kegan Paul, Trench, Trubner & Company), 1–11. doi: 10.1037/11496-001

Yaron, I., Melloni, L., Pitts, M., and Mudrik, L. (2022). The ConTraSt database for analysing and comparing empirical studies of consciousness theories. *Nat. Hum. Behav.* 6, 593–604. doi: 10.1038/s41562-021-01284-5

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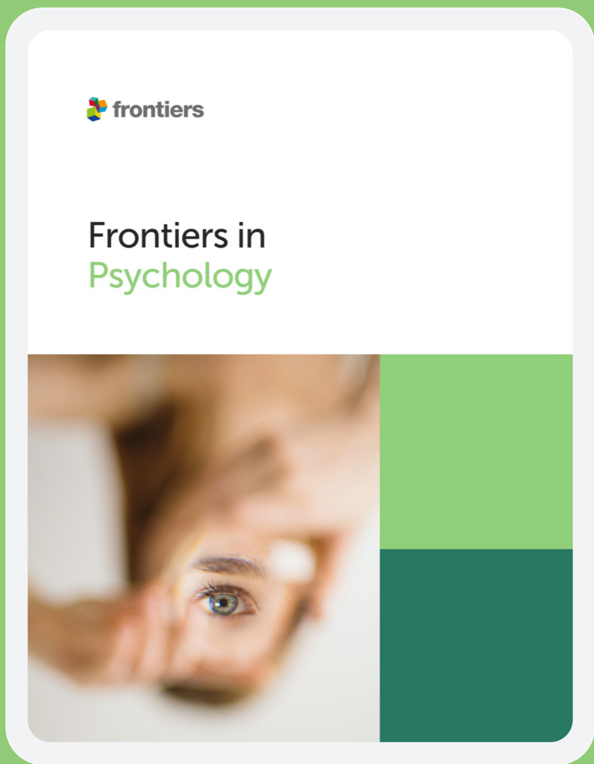

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