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# Neurobiology of Consciousness: Current Research and Perspectives

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*Abstract:*
Scientific, objective approach to consciousness has allowed to obtain some experimental data concerning brain activity, ignoring, however, the long-standing philosophical tradition. Spectacular development of neuroscience which has been observed recently made this dissonance particularly noticeable. The paper addresses the main problems of discrepancy between neurobiological research and philosophical perspective. Current opinions concerning neural correlates and models of consciousness are discussed, as well as the problems of working memory, attention, self, and disorders of consciousness. A new neurobiological approach to describe brain function in terms of brain connectivity (so-called connectome) is also presented. Finally, the need to introduce at least some aspects of philosophical approach directly into neurobiological research of consciousness is postulated.
*Keywords:* consciousness, attention, self, working memory, brain networks, disorders of consciousness, neural correlates of consciousness.

## 1. Introduction

In this paper I will try to present current findings and views in the main areas of neurobiological research concerning consciousness. I will endeavor to find some consistency among the vast number of papers with various topics and methodology that can be found in scientific databases every year. I will also discuss some shortcomings of the scientific approach to consciousness, the general lack of understanding of these problems by neurobiologists and the need to incorporate philosophical perspective into their studies.

Consciousness is a complex and ambiguous concept enjoying a long tradition of analyses that still eludes our understanding and lacks any universal definition. It is impossible to be certain that all neurobiologists use the same definition of consciousness because many of them do not define the subject of their research. However, one can assume that most authors apply the definition similar to the one used by G.M. Edelman, J.A. Gally and J. Baars, who define consciousness as "a dynamic, integrated, multimodal mental process entailed by physical events occurring in the forebrain" [42]. They also add that



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> conscious processes arise spontaneously and display intentionality, i. e., for the most part, each is about something […] consciousness is necessarily subjective and internal […] but its contents can often be inferred from animal behavior or verbal report [42].

However, all attempts to match empirical data obtained by neurobiology with philosophical concepts of subjectivity or consciousness lead to major problems. There is a large rift between empirical sciences and philosophy, resulting from different approaches and methods as well as from progressing specialization (especially in life science). The precise meaning of such categories as consciousness or subjectivity is of minor importance for many neurobiologists. Neurobiological research is usually focused on proper application of various advanced techniques (such as methods of physiology and genetics, neuroimaging and computational methods) and interpretation of data in order to identify brain areas involved in psychical functions. Much attention is also paid to selecting psychological tests appropriate for analysis of the psychic state under study. There are many terms like awareness, consciousness, self, working memory or representation, that are frequently used in scientific papers without explaining their precise meaning. Limitations of techniques used in research as well as the great complexity of human brain lead to a huge number of data, but there is no model of consciousness universally accepted among neurobiologists.

## 2. Scientific Approach and its Weaknesses

We should not expect to fully explain the phenomenon of consciousness merely by accumulating neurobiological data, even the ones obtained using such advanced techniques like fMRI (functional magnetic resonance imaging) or PET (positron emission tomography). To achieve this goal we need to find a common ground to share ideas between neurobiology and humanities. This important problem is well described by Thomas Metzinger, who states:

> in the now flowering interdisciplinary field of research on consciousness there are two rather extreme ways of avoiding the problem. One is the attempt to proceed in a highly pragmatic way, simply generating empirical data without ever getting clear about what the explanandum of such an enterprise actually is […] What are the actual entities between which an explanatory relationship is to be established? Especially when pressed by the humanities, hard scientists should at least be able to state clearly what it is they want to know, what the target of their research is, an what, from their perspective, would count as a successful explanation. The other extreme is something that is frequently found in philosophy, particularly in the best philosophy of mind. I call it "analytical scholasticism". It consists in an equally dangerous tendency toward arrogant armchair theorizing, at the same time ignoring first-person phenomenological as well as third-person empirical constraints in the formation of one's basic conceptual tools [81, pp. 17-18].

Most researchers concentrate on obtaining experimental data even without defining the analyzed phenomenon. Therefore, it is extremely rare for researchers to provide a reader with the description of their philosophical assumptions. Bernard J. Baars is one of the authors who are aware (more or less) of the main problem of different perspectives in the analyses of consciousness. He is strongly convinced that first-person perspective can be linked with the scientific third-person perspective.

> We can only study something if we can treat it as a variable, comparing its presence to its absence […] Consciousness has seemed to be different from all other scientific concepts; it has been extraordinarily difficult to treat it as a variable. The persistent



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> pattern over centuries has been to see our own experience as the only psychological domain that can be conceived, one that has no kinship to any conceivable comparison condition […] It is actually quite possible to compare conscious events that people can report accurately to unconscious ones that can be inferred and studied indirectly […] We can call this method contrastive phenomenology, to emphasize the involvement of private experience. Phenomenology is the study of consciousness based on subjective reports; in scientific practice we always supplement subjective reports with objectively verifiable methods [10, pp. 11-12].

Unfortunately, this awareness of the problem is often accompanied by total disregard of philosophical perspective, as presented by Edelman, Gally and Baars who declare:

> we believe, that such a biological approach can address and even dispose of several concerns articulated by philosophers of mind and others. We propose that a biological account of consciousness does not require metaphysical proposals, mathematical reduction, or "strange physics". We also maintain that previously argued categories such as selfhood and phenomenal experience can be explained biologically in terms of patterns of neural activity [42].

## 3. Models of Consciousness

This kind of approach is common among neurobiologists who apply advanced techniques (as mentioned earlier) in search of brain areas that are believed to give rise to consciousness. This means, in fact, monitoring of brain activity during conscious processes and attributing the increased activity to the generation of consciousness. Current research based on this assumption revealed involvement of various cortical areas (especially frontal, parietal and cingulate cortex), thalamus and reticular formation as well as some areas corresponding to episodic and semantic memory [36]. There are still controversies concerning the extent of the brain specialization, but there are brain regions identified that are specialized in analysis of faces, bodies, places, visually presented words and even thinking about another person's thoughts [58]. Such specialization substantially limits brain capacity to process multiple items simultaneously, but the extent of limitation depends on the category of objects [27]. Some data obtained by various techniques support the hypothesis that cortical areas contributing to consciousness exhibit enhanced synchrony in the gamma frequency band that may give rise to the global workspace (according to the global workspace theory consciousness results from integration of activity of many neurons in various brain areas) [42]. For many years main debates concerning models of consciousness have occurred between supporters of two main opposite theories – the global workspace theory [42] and Ned Block theory of phenomenal consciousness (P-consciousness) and access consciousness (A- consciousness). The Block's distinction of two kinds of consciousness was at first purely theoretical [21], but it has also been supported by empirical data [22], [23], [59], [67], [68], [91], [118], [121]. Both theories has been united in another model suggested by A. Raffone and M. Pantani [104].

Expansion of experimental data accompanied by occurrence of new techniques and approaches resulted in more theories of consciousness, such as first-order representationalism, information integration theory, recurrent processing theory or higher-order representationalism. The first-order representationalism assumes that consciousness consists of sensory representations available directly for various activities to the subject. According to the authors the theory is philosophical but it is able to explain both general consciousness (what makes a particular state conscious in general) and specific consciousness (phenomenal quality of a conscious state). They suggest the existence of neural correlates of general consciousness (prefrontal cortex, posterior parietal cortex, and non-specific thalamic nuclei) and specific consciousness (sensory cortex and specific thalamic nuclei), providing experimental data supporting the first-order representationalism



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theory [79]. Higher-order theories assume that conscious awareness depends on higher-order mental representations (representing oneself as being in particular mental states). There is also a large body of empirical evidence supporting the higher-order model of consciousness, but also some data disproving the notion (such as that prefrontal cortex lesion does not abolish awareness and the activity of prefrontal cortex does not reflect awareness but attention). Similarly to the previously mentioned model (the first-order representationalism) the higher-order theory resulted from philosophical approach and explains consciousness in terms of higher-order awareness. According to the authors both consciousness and metacognition (important for mental processes and behavior) involve higher-order psychological states. There is some analogy between higher-order awareness and metacognition (mainly the possibility of misrepresentation), but the utility for psychological processing seems to be the greatest difference between the two phenomena [69], [108]. Another theoretical model of consciousness which has been created lately is the consciousness state space (CSS) model. The authors describe it as a "phenomenological model for consciousness and selfhood which relates time, awareness, and emotion within one framework" [17]. Like other models, it is supported by a substantial amount of empirical data and enables to describe the relationship between various aspects of conscious experience. The model assumes two categories of consciousness: core and extended consciousness which can be applied to all phenomenological states. Core consciousness supports minimal selfhood (its scope is here and now) while extended consciousness supports narrative selfhood (involves personal identity across time, memory, imagination and conceptual thought). The consciousness state space (CSS) described in the model is a phenomenological space formed by three dimensions – time, awareness and emotion. The model is supported by neurobiological data, which provide neural correlates for all three dimensions, as well as for core consciousness and extended consciousness [17].

## 4. Re-evaluation of Experimental Data

Nevertheless, recent studies proved that some previously established data and theories should be reconsidered. For example, some neural processes believed to reflect the neural correlates of consciousness (P300, gamma frequency band, long-range integration) seem to occur even without conscious experience [6]. There are also suggestions that we should look for neural constituents of consciousness instead of "traditional" neural correlates of consciousness [83]. Another problem concerns theoretical basis of research of consciousness. Most of the data have been obtained during conscious perception and contrasted with trials lacking conscious perception, as based on the basic approach designed by B.J. Baars [9]. It is currently suggested that such approach does not reveal neural correlates of consciousness, but lead to some processes prior to conscious experience, or following it [7]. Some researchers look for new paradigms like the Reflexive Imagery Task, in which conscious content is triggered unintentionally and reliably (as a function of external control). The set-related imagery cannot be suppressed by participants instructed to not sub-vocalize the name of a stimulus object [2]. The approach based on the contrast between conscious and unconscious experience resulted in recognizing two aspects of consciousness: content of consciousness (awareness) and level of consciousness (wakefulness), widely used also in clinical diagnosis [70]. However, some researchers suggest a theoretical integration of studies of the contents of consciousness and the level of consciousness [13]. New ideas of levels of consciousness, its psychophysical measurements and relations to neural correlates of consciousness has also been introduced by T. Bachmann [12].

## 5. Attention and Consciousness

Another important and thoroughly investigated problem concerns the importance of attention for conscious processes. Current research identified brain areas involved in the three attention systems, related to different components of attention and using different neurotransmitters (orienting



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network, alerting network and executive network). It is believed that attention (especially the executive network) is extremely important for voluntary control of cognitive processes, emotions and behaviour as well as for focal awareness. Attention is crucial for perception of objects but also for thinking (additional activity in frontal and parietal cortex was observed after focusing attention on mental representations). There is an extensive discussion concerning attention and consciousness. Some researchers support the notion that attention and consciousness are two completely separate processes, while the others believe them to be strongly connected or even being two aspects of one phenomenon. There are some experimental data suggesting the possibility of conscious experience without attention, but some authors attribute this phenomenon to the involvement of different kinds of attention (namely focal awareness and ambient awareness), not the lack of attention. The complexity of attentional processes and various kind of attention (apart from focal awareness and ambient awareness) results in ambiguity of interpretations [6], [11], [65], [72], [89], [101], [105], [106], [127], [137].

## 6. Problem of "Self" and Default Mode Network

One of the most important issues in research of consciousness is explaining the problem of "self" (generally understood as the neural correlates of self). Neurobiological data suggest a major involvement of cortical midline structures (CMS): medial prefrontal cortex, medial orbital prefrontal cortex, medial parietal cortex, anterior and posterior cingulate cortex in self-consciousness [1], [93], [102]. Detailed study revealed involvement of different brain structures in forming various aspects of self-consciousness. For example activity of ventral and dorsal medial prefrontal cortex and the posterior cingulate cortex is higher when reflecting on the present self than when reflecting on the past self or the other person. Other research proved considerable specialization of medial prefrontal cortex, which ventral part contains information relevant for "self", whereas the dorsal region is responsible for decision-making processes and evaluation (concerning "self" and "other") [31], [33], [121], [131]. The crucial role of posterior cingulate cortex [25], as well as possible interactions with the mirror neuron system must also be considered [116], [110]. There is a considerable discrepancy between researchers in using specific terms, especially self-referential processing and self-reflection, which are often treated as ones having the same meaning.

> Several studies have investigated the neural correlates of self-reflection or self-referential processing. In the literature these terms are used interchangeably and refer to the evaluation process used to decide whether certain environmental cues apply to one's self or not. Technically, self-referential processing is a broader concept in which all information that somehow refers to oneself is processed and encompasses subconscious as well as conscious processing. Self-reflective processing on the other hand implies a conscious process in which a decision is made regarding oneself [131].

Most researchers involved in studies of "self" and "self-consciousness" use the so called self-referential paradigm, based on the self-reference effect [120]. This paradigm uses self-reflection "in which subjects are presented with trait adjectives or sentences and are asked whether the trait or sentence applies to them" [131]. Discrimination between "self" and "other" is of paramount importance for social interactions and depends strongly on the mechanisms of mentalizing explained as the theory of mind [15], [133]. The ability to discriminate between "self" and "other" is attributed to the activity of the posterior cingulate cortex, ventral medial prefrontal cortex and temporo-parietal junction [32], [46], [59], [73], [74], [115]. In general, majority of authors focus on acquiring a lot of neurobiological data in their studies of self. However, a new trend of looking for broader concepts of self can be observed in recent years. Some authors, like G. Northoff attempt a



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more philosophical approach [92], try to give more thought to possible interpretations of the term "self", like K. Musholt [86] or suggest various models, such as extended forward model [119] or pattern theory of self [49].

Apart from new models and approaches an important discovery of the direct link between "self" (neural correlates of self) and the so-called "default mode network" opened new perspectives [85], [102], [110]. Raichle et al. demonstrated in 2001 the presence of an extremely important brain network, the "default mode network" (DMN). DMN exhibits increased activity during the resting state as compared to the attention-demanding cognitive tasks, which in turn are governed by the central executive network (CEN, comprising mainly dorsolateral prefrontal cortex and posterior parietal cortex). DMN is responsible for cognitive processes in the brain that are independent on external stimuli (self-focused spontaneous cognition), such as self-reflective thoughts, autobiographical reminiscences or mind-wandering. Current research suggests influence of DMN dysfunctions on ADHD, autism, Alzheimer's disease, depression and schizophrenia. Some authors support the idea of another network, the so-called "salience network" (SN), selecting internal and external signals and controlling subsequent processes in either DMN or CEN, also modulating the activity of both networks. DMN primarily involves the anterior and posterior cingulate cortex, medial prefrontal cortex, precuneus, inferior parietal cortex (angular gyrus region) and inferior temporal cortex. Dorsal anterior cingulate cortex and anterior insula are involved in many complex cognitive and emotional processes like empathy [4], [78], [80], [84], [107], [117], [134]. Recent empirical data suggest altered DMN function in such states of consciousness as sleep, general anesthesia and hypnosis [56]. Furthermore, the network perspective in search of the link between brain and behavior is now popular among researchers [47], [96], [99], [109], [122], [139]. The most ambitious attempt of mapping human brain connectivity as a basis of behavior started in 2013 as the Human Connectome Project [132].

It is impossible in this paper to fully discuss all aspects of self-consciousness, especially from various perspectives. The analyses presented here focused only on two aspects of an extremely complicated topic – methodological problem and empirical data on neural correlates of the self, although such choices are definitely arbitrary. Therefore, some problems concerning self-consciousness, such as complexity of self-consciousness, emergent phenomena, or the relation between consciousness and self-consciousness will be only mentioned briefly. It may be noted, that these problems are largely neglected in most research papers. It has already been mentioned that most authors "reduce" the "self" to the application of the "self-referential paradigm" and focus on experimental procedures to locate neural correlates of the self. However, there are also interesting and precise analyses of the complexity of the self in the search of widely accepted model, based on experimental neurobiological data [26], [48], [81], [82]. For example U. Neisser distinguish between five aspects of self – ecological, interpersonal, extended, private and conceptual [87], while S. Gallagher focuses on the distinctions between "minimal self" and "narrative self" as well as on differences between the sense of self-agency and the sense of self-ownership [48]. The complexity of self-consciousness is also taken into account in psychological analyses [34], [64] or research on some diseases [5], [53], [113], [114]. A lot of effort has been put in recent years into investigating the importance of bodily self-consciousness (the pre-reflective and non-conceptual representation of body-related information) for the model of self-consciousness. Many aspects of the bodily self-consciousness has been analyzed, such as its visual [44], vestibular [100] or multisensory mechanisms of bodily self-consciousness [8, 18], bodily ownership, self-location and peripersonal space [19], [20], [90], [112], out-of-body experiences [71] or illusory own-body perceptions [94].

Another area of interest concerns both developmental and functional link between self-consciousness and episodic autobiographical memory [76], [77], [125]. The problem has been analyzed since the important distinction between different memory systems in 1983 [123]. E. Tulving described three distinct memory systems – procedural, semantic, and episodic, and their



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relations to various kinds of consciousness – anoetic, noetic and autonoetic consciousness, respectively, using terminology originally introduced by E. Husserl [123], [124]. Tulving states:

> Each of the three memory systems, in addition to other ways in which it differs from others, is characterized by a different kind of consciousness. I will refer to the three kinds of consciousness as anoetic (non-knowing), noetic (knowing), and autonoetic (self-knowing) [123, p. 3].

Although the distinction between three memory systems and three kinds of memory is widely used by many authors, the nature of the links between the respective memory systems and types of consciousness is unclear. The "link" is usually described as the "relation", "interconnection" or "correlation" between memory and consciousness, consciousness as a "defining property" of memory, or even identified with each other (episodic memory with autonoetic consciousness, semantic memory with noetic consciousness) [51], [124]. S.B. Klein is one of few researchers who actually ask this question.

> So what exactly is the connection between autonoetic awareness and episodic memory? Two possibilities present themselves. Either (as commonly assumed, though seldom stated), autonoetic awareness is (1) intrinsic (i.e., necessary) to episodic memory— i.e., it is a part, or constituent, of 'episodic' content, or (2) it has a relational (i.e., contingent) connection to memory content— i.e., while under normal circumstances it is observed to be coextensive with 'episodic' content, this connection is one of contingency rather than necessity [63, p. 3].

Current experimental findings suggest that the relations between memory systems and various kinds of consciousness are more complex than assumed in the original distinctions. Klein supports the idea of the relation between functionally independent autonoetic consciousness and episodic memory content, rather than the notion of autonoetic consciousness being an intrinsic property of episodic content [63]. Autonoetic self-consciousness must also be distinguished from noetic self-awareness (semantic knowledge about oneself) [128]. Various kinds of consciousness (anoetic, noetic and autonoetic) are often treated as emergent phenomena and discussed as a part of human development [61], [88] or from the evolutionary perspective [43], [95]. Tulving is convinced "that only human beings possess 'autonoetic' episodic memory and the ability to mentally travel into the past and into the future, and that in that sense they are unique" [126, p. 4], but there is a distinct possibility, that to a certain extent, it is also present in some mammals (not only primates) and birds [43]. It is suggested that various levels of consciousness emerge in subsequent stages of ontogenesis [61], [88], and that anoetic (primary) consciousness has a fundamental importance for emergence of higher forms of consciousness [128], [129], [130].

The theories described above are a good example of the widely approved opinion on the relation between consciousness and self-consciousness. It is usually assumed by researchers that self-consciousness is just an aspect of consciousness. The notion was explicitly expressed by F. Crick & C. Koch [29] and further developed in another paper:

> There are many forms of consciousness, such as those associated with seeing, thinking, emotion, pain, and so on. Self-consciousness—that is, the self-referential aspect of consciousness—is probably a special case of consciousness [30, p. 97].

Some other analyses from philosophical point of view describe the relation a little bit differently. For example, U. Kriegel distinguishes transitive and intransitive self-consciousness (on the basis of D. Rosenthal's distinction between transitive and intransitive consciousness) and claims that consciousness depends upon intransitive self-consciousness [66]. T. Bayne argues that self-



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consciousness constrains phenomenal unity of consciousness [16], and according to Zahavi and Parnas "the ipseity, the normally tacit or unnoticed 'myness' of the experience […] is a precondition or a medium of any natural, spontaneous and absorbed intentionality [138, p. 700].

## 7. Working Memory and Consciousness

Another important area of research related to the phenomenon of consciousness concerns working memory - ability to actively maintain and manipulate information (abstract or of a given sensory modality) that is kept concurrently in an easily retrievable state. It is critical for cognition, e.g. for language abilities, problem solving or achieving a goal. The link between working memory and consciousness is unclear. Some authors believe working memory content is always conscious (working memory content equals conscious experience) [9], [14], whereas others treat working memory content and conscious experience as partially overlapping [28] or even completely separate [57], [116]. There are several models of working memory, the most influential being the model of A. Baddeley, suggesting that working memory consists of multiple components (central executive, phonological loop, visuo-spatial sketch pad and episodic buffer) [14]. Other models, like feature model or embedded-processes model, do not propose components of working memory but suggest a critical role of attention [28]. Current research revealed that using words about perception and action leads to activation of neurons in sensory and motor areas of the brain, apart from language areas. The phenomenon was proved also for metaphors [50]. Such findings supported the hypothesis of embodied cognition, which is now accepted by many authors both in cognitive science and in neurobiological research [35], [60], [62], [75], [111], [135]. Problem of relations between cognition and language was discussed by many authors and various solutions were suggested. One of interesting hypotheses addressing the issue is a dual model by L. Perlovsky, assuming that every concept (model) has two parts – linguistic and cognitive, and the connections between them is inborn. Experience allows to acquire the specific content of both parts but inborn links facilitate appropriate word-object associations. It is suggested that people are usually conscious only of the language part of representation, especially for abstract ideas which cannot be directly perceived by the senses [97], [98].

## 8. Studies of Disorders of Consciousness

The last important research area discussed here is related to clinical diagnosis of the disorders of consciousness (coma, vegetative state/unresponsive wakefulness syndrome, minimally conscious state). Diagnosis of patients with disorders of consciousness is now conducted using standardized behavioral test (e.g. Coma Recovery Scale) in order to avoid misdiagnosis [55]. Some researchers look for new methods of assessing levels of consciousness, as such a diagnosis has great ethical, personal and economical consequences for patients and medical staff [24], [41], [54]. In recent years a lot of effort has been put into studies of disorders of consciousness (minimally conscious state, unresponsive wakefulness syndrome/vegetative state, and coma) using resting-state fMRI as a tool to assess intrinsic functional connectivity of brain networks. Researchers found that intrinsic functional connectivity in many brain regions (especially in the posterior cingulate cortex and precuneus) significantly correlated with consciousness level and chances of recovery [3], [136]. Other studies differentiated between various disorders of consciousness on the basis of functional connectivity for the default mode network (DMN), executive network, salience network (SN), auditory, sensorimotor and visual networks [37], [38]. It was also stated that salience network connectivity (especially between the supragenual anterior cingulate cortex and left anterior insula) correlates with behavioral signs of consciousness, whereas DMN connectivity (especially between the posterior cingulate cortex and left lateral parietal cortex) is a good prediction of recovery of consciousness [103]. This line of study is of special importance because of the practical impact of



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its results (influencing decisions in medical practice), apart from its involvement in describing the phenomenon of consciousness.

## 9. Closing Remarks

Despite the tremendous effort and hundreds of papers published yearly, researchers are still unable to define, precisely describe or characterize the fascinating phenomenon of consciousness. In general, such a vast amount of experimental work can be roughly grouped into several areas discussed above, such as the study of working memory, the role of attention in conscious processes, the problem of "self" (especially the importance of default mode network), the increasingly popular network perspective (brain connectivity – connectomics), and clinical diagnosis of the disorders of consciousness. A lot of effort is also placed on developing new experimental techniques as well as on perfecting the methods of data analysis, which is usually the highest priority for researchers. These methods shed new light on various experimental data and forced researchers to reconsider some of the generally accepted explanations, with the most notable example of the P300 wave (in EEG) as an indicator of consciousness. In fact, the ongoing research on consciousness strongly resembles the effort of building a giant jigsaw puzzle by working on various parts separately and hoping that the whole picture would eventually emerge. However, the main reason for experimental results to be treated with caution stems from the basic difficulty of connecting two different perspectives in the studies of consciousness. There is no balance between these perspectives: while the objective one getting a great, professional care, the subjective "aspect" is usually reduced to the short description of the task (test) involved. Fortunately, there are some attempts to improve this "aspect" of research, usually by introducing new tasks (like the Reflexive Imagery Task), but the main question of "what" is really studied there remains valid. Most researchers are impervious to the problem, focusing solely on the proper experimental techniques and data analysis. It is still a unique attitude, but the need to integrate various perspectives has been recognized and attempts of more philosophical approach have been made by some authors in recent years [39], [40], [52], [86], [92]. Is it possible to conclude that scientific data unambiguously justify reductionism? It is probable that the concept is accepted by most researchers and fundamental for their methodology, but the universal lack of explanation in scientific papers does not allow for drawing this conclusion. There are examples of different positions, like the one presented by Todd E. Feinberg, which he calls a weakly emergent nonreductive physicalism or neurobiological naturalism [45]. We may hope that the future research will give some strong arguments supporting one solution and cognitive science eventually plays an important role in integrating various perspectives.

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