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Consciousness science: real progress and lingering misconceptions☆

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Nobel Laureate Paul Krugman once remarked that engaging the public about economic theories is hard, partly because everybody feels they are entitled to opine about the economy even if they have no formal training in economics (see: http://web.mit.edu/krugman/www/virus.html). Perhaps because we are all conscious, the same sometimes happens in the field of consciousness research. Like Krugman, we think this is a troubling state of affairs that needs to be rectified.

Consciousness used to be a controversial topic of study. Not only during the heyday of behaviorism, but also during the rise of cognitive science in the 1970s and 1980s, only a few senior scientists (such as Gerald Edelman and Francis Crick), who had first achieved success and job security in completely unrelated fields, felt free to attack this final, big question. But how things have changed in the past 20 years! There are now numerous laboratories around the world, led by scientists at various career stages, dedicated exclusively to the study of consciousness. Just as in the most mature areas in psychology and neuroscience, concepts and phenomena are being carefully analyzed, distinguished, explained, and taxonomized.

Readers of Paller and Suzuki's recent article on consciousness in this journal [1] may conclude that the field still faces the question of whether consciousness is a valid topic for scientific inquiry at all. Although Paller and Suzuki go on to argue against this view, there are still those, both in the general public and within the scientific community, who believe this is the case. Consciousness science, however, has long emerged from the dark ages when this was a relevant issue, and moved away from simple intuitions and generalizations. Current debates in the field – and there are fierce debates – focus on the use of hard empirical evidence to assess the relative merits of theories grounded in established scientific disciplines. Exciting empirical findings have led to a great deal of progress, shedding light on fundamental questions regarding this central aspect of our existence.

We now know, contrary to many people's introspective intuitions, that attention and awareness are dissociable: attention of various types can function in the absence of consciousness [2] and there is some evidence that there may be conscious experience without attention or report [3]. We now have an idea of the kinds of cognitive and perceptual processing that can occur in the absence of awareness, and how these may differ from conscious processing [4]. We are developing an understanding of the neural and cognitive mechanisms of metacognition, or insight into one's own awareness and performance [5]. Recent years have also seen a great leap forward in our understanding of the brain activity associated with different levels of consciousness, including the development of methods to detect its presence in deep sleep as well as anesthetized [6] and neurologically impaired patients [7]; these enable better diagnostic practices in disorders of consciousness and raise the possibility of detecting preserved awareness in vegetative-state patients [8].

These empirical advances are accompanied by the ongoing development and testing of new behavioral methods and quantitative measures for assessing levels and types of awareness, so that we can go beyond simply asking subjects, 'Are you aware of that?' [9]. Whereas in the early days many theories of consciousness took the form of educated personal speculations, theories are now systematically arbitrated on empirical grounds, not just in a post hoc fashion but based on their empirical predictions, as many labs dedicate efforts to directly testing detailed, theory-generated hypotheses [10]. Consciousness is now studied at the levels of behavior, neuroscience, and molecular mechanisms, in patients as well as healthy subjects and animals. This interdisciplinary effort encompasses the fields of psychology, biology, physics, and philosophy.

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Keywords: consciousness; awareness; metacognition; attention; disorders of consciousness; conscious and unconscious processing.

1364-6613/
 http://dx.doi.org/10.1016/j.tics.2014.09.004

There is a lively interchange of ideas concerning empirical results and their philosophical implications, leading to radical changes in the philosophy of mind. Anyone interested should visit the annual meeting of the Association for the Scientific Study of Consciousness (http://www.theassc.org/), and witness this spirited exchange. Perhaps most importantly, these efforts lead to real and applicable results, with implications for both theoretical understanding and applied clinical settings.

Have we come to a fundamental understanding of consciousness yet? Of course not. But it is clear that the field is maturing and making significant progress, converging on approaches to understanding this most enigmatic phenomenon. The science of consciousness does not suffer from a lack of public engagement; on the contrary, it is often discussed in the popular press. However, as Paller and Suzuki [1] point out, the public should be made aware of the most recent developments in the field. Such engagement should strive to make clear the distinction between rigorous, testable scientific ideas and outlandish speculations on the nature of consciousness – such as the view that electrons are conscious – that may easily attract media attention but are not grounded in empirical research.

Consciousness science is here to stay. The great empirical strides made in recent years, the continuing development of rigorous approaches, and the enthusiasm of new generations of researchers lend themselves to a feeling of optimism. We will, eventually, crack this natural phenomenon that is so fundamental to our very being.

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Response to Block *et al.*: first-person perspectives are both necessary and troublesome for consciousness science

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We are grateful to Ned Block and co-authors for their commentary piece, 'Consciousness science: real progress and lingering misconceptions' [1], which expands on the arguments we put forward in our earlier Science and Society article [2].

Because people are conscious, it is natural for them to have views about the basis of their own conscious experiences and, by extension, about the basis of consciousness generally. Block and colleagues open their piece by pointing out the 'troubling state of affairs' that this causes.

People can introspectively reach the conclusion that consciousness is a form of energy or something akin to it that arises in essence from a nonphysical source to generate their unique mental lives. Consequently, consciousness is believed to lie outside the realm of scientific investigation. This introspective conclusion may have an understandable basis in the way consciousness functions as a vehicle for compartmentalizing the intentions of self and others [3] — but it can be seriously misleading.

Introspection can nevertheless yield helpful foundations for consciousness research. Consider that we routinely switch back and forth between conscious and unconscious modes of information processing. For instance, when you begin to write a paper, you consciously formulate ideas that you want to convey, and if you get lucky, appropriate sentences mysteriously emerge from your unconscious processing. If not, you consciously toy with the ideas in various ways, and if still no good sentences emerge, you may become flustered or decide to procrastinate.

Consciousness reflects a specific mode of information processing wherein information is explicitly available for intentional (goal-directed) control of attention, memory, and thoughts. By contrast, information can remain largely intangible to intentional control mechanisms via the unconscious mode of processing, but still automatically direct attention, evoke memory, and induce thoughts. A major scientific challenge is to understand the neurocomputational mechanisms of both conscious and unconscious processing, as well as their interactions.

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1364-6613/
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The source of consciousness

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Why does a relentless stream of experiences normally fill your mind? No answer is entirely satisfactory. We are not sure how the normal operation of the human brain might exude subjective experiences. Consciousness can thus seem miraculous, and research on consciousness a waste of time and money, ultimately doomed to fail. Yet, there are good reasons for optimism that should be shared with the public to justify research in this area.

Inherently beyond science?

The opinion that conscious experiences lie outside the realm of scientific inquiry regularly appears in the press (e.g., [1]). If the origins of consciousness are supernatural or otherwise beyond human understanding, there is no hope of addressing the question scientifically. Moreover, we are hampered by a lack of objective measures to index consciousness. Yet this is precisely what scientists are now striving to identify using various measures of information exchange in the brain [2,3]. Further research will be needed to validate these new measures, but they potentially represent a step toward testing specific hypotheses about consciousness and thus making it less mysterious.

Importantly, the conviction that consciousness is ineffable may reflect assumptions people commonly make about consciousness based on their own introspections. If these assumptions are incorrect, the reasoning used to take consciousness research off the table may be faulty. Here, we point out some flaws in common intuitions about consciousness. In light of these flaws, we also highlight a broad range of promising directions for research on consciousness and strongly advocate against the position that this fundamental facet of the human mind will forever be beyond human understanding.

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1364-6613/
 http://dx.doi.org/10.1016/j.tics.2014.05.012

Crucial ingredients for awareness

You may think that if you attentively inspect something you must be aware of it. Not true. A short time experiencing motion-induced blindness is convincing (see Movie S1 in the online version at http://dx.doi.org/10.1016/j.tics.2014.05.012); bright discs completely vanish, even when full attention is allocated to the stimuli.

You may think that sensing, analyzing, and deciding necessitate consciousness. Not necessarily. You can have no awareness of a briefly flashed number but still accurately assess its value, perform a mathematical operation, and produce an appropriate answer [4].

If neither strong sensory stimulation, nor paying attention, nor deeply analyzing guarantees awareness, what is the crucial ingredient? One answer is that awareness depends on a reciprocal exchange of information across multiple areas in the cerebral cortex [5]. Consider how damage to the primary visual cortex usually blocks visual awareness, producing blindness. Yet, a patient might correctly discriminate moving objects and not consciously see them, demonstrating 'blindsight'. In these cases, visual discrimination without awareness presumably reflects restricted cortical processing without the reverberating exchange of information [6]. In a healthy individual, the sensation of movement can be experienced when cortical motion area V5 is artificially activated with a dynamic magnetic field, but not if communication from V5 to primary visual cortex is disrupted [7]. For motion perception, then, and perhaps for other conscious experiences, exchange of information between specific cortical areas seems to be essential.

According to the information integration theory of consciousness, there is something about the exchange of information itself that constitutes consciousness [8]. That is, an experience would be conscious only to the extent that information exchange is complex. Roughly speaking, complexity here pertains to the number of intricately interrelated ideas generated within a web of local and global information exchange. There would be only a minimal level of consciousness when the brain supports only a small number of ideas or a large number of ideas that are disconnected. A rich level of consciousness would require a suitable mixture of short-, medium-, and long-range neuronal connections that can support a large number of interrelated ideas, a mixture that indeed characterizes the anatomy of the cerebral cortex.

Awareness of the self

The awareness we each have of our own body and our place in the world seems to be distinctly natural and fundamental. Yet the conscious experience of having a body can be bizarrely disrupted in patients with right parietal damage, who sometimes deny ownership of an entire arm. The rubber-hand illusion is another striking phenomenon, whereby seeing someone rubbing a fake hand while feeling the simultaneous tactile sensation on your own hand momentarily makes you feel that the fake hand is yours. In an even more extreme way, altered neural activity can produce an out-of-body experience [9].

These unusual perceptual experiences are no less 'real' than the sensation of a self inside a body. This standard way we each think of our self is a manufactured sensation, learned on the basis of sensory relationships across modalities. Awareness of a self inhabiting a body is not as obligatory as it seems: it is likely to have evolved for a behavioral advantage.

Why does the brain construct the sensation of a self inside a body? One answer appeals to the idea that you fare better in a social environment when you can attend to your own needs and predict what will happen next, including what other people are going to do. To make this work, specific brain mechanisms evolved to construct models of the attention and intentions of others and to localize them in the corresponding people's heads. The social neuroscience theory of consciousness [10] postulates that these same brain mechanisms were adapted to construct a model of one's own attention and intentions, localized in one's own head and perceived as consciousness. If so, a primary function of consciousness is to allow us to predict our own behavior.

Above and below the surface

Conscious experiences must be understood in the context of neural processing that transpires without a concomitant conscious experience. Consider memory functions, for example. We can each retrieve a set of conscious memories that forms a record of our life up to the present moment [11]. Nonetheless, in addition to our ability to consciously remember important life events, these events establish unconscious memories that later influence our moods, thoughts, and behaviors without any concomitant awareness of memory retrieval [12].

We may think we know the full chain of reasoning behind a well-considered decision. Such decisions may indeed rely on the broad exchange of information in the brain characteristic of conscious processing. Conscious reasoning integrates processing across many cortical networks so as to systematically influence how key factors are weighted in reaching a decision. By contrast, unconscious processing allows for the parallel accrual of information in many separate cortical networks, independently weighted based on factors such as statistical reliability, potentially forming the basis of an astute gut decision or coalescing into a flash of insight, and influencing our conscious decisions in ways we never suspect.

We feel fully in control of most of our actions. However, substantiating these impressions and confirming the existence of 'free will' is challenging. It is likely that a conscious action, and conscious experiences generally, emerge gradually from unconscious precursors in the brain. Indeed, measures of brain activity can probabilistically predict a left-versus-right-handed action seconds before people think they make the decision [13], suggesting that snap judgments actually arise from protracted processes. When testing specific ideas about the neural underpinnings of a conscious action or experience, one ongoing challenge is to disentangle the processing that is essential from what may merely precede or follow [14]. Moreover, the neural processes that generate the subjective timing of a conscious decision that is seemingly instantaneous may be separate from the more protracted, unconscious processes that generate the content of the decision. The feeling of freely deciding at the precise time of our choosing may be a widespread illusion, albeit a beneficial one that promotes moral behavior and helps us to flourish as social beings.

Understanding consciousness

Science is gradually making consciousness more understandable, although no less amazing. When we recognize the shortcomings of common assumptions about consciousness, we are in a better position to develop an integrative understanding of the origin, evolution, development, and subjectivity of consciousness. Instead of emphasizing a single paradigm for examining awareness, we can be enriched by enlisting a variety of approaches, combining functional, biological, social, and computational perspectives.

There is ample reason to be optimistic about future scientific inquiries into consciousness and about the benefits that this knowledge could bring for society. For example, continuing efforts could characterize types of neural interaction that are essential for consciousness [2,3,14], and thus inform concerns about human and animal rights, help to explain and treat diseases that impinge on consciousness, and help to perpetuate environments and technologies that enrich our conscious experience and contribute to the well-being of individuals and of our society.

Although conscious experiences are inherently private, a rational scientific worldview cannot disregard the fact that people have subjective experiences, or that science relies on conscious perception and reasoning. Thus, our position [15] is that research on human consciousness belongs within

the purview of science, despite philosophical or religious arguments to the contrary. The foregoing examples show that a wide range of scientific perspectives can offer useful clues about consciousness. The necessary reliance on subjective report requires great care, but increasing the validity of these reports is possible: for example, by experimentally constraining subjective choices as in psychophysics, by sharpening people's introspective abilities with meditation training, and by steadily advancing our understanding of neural mechanisms of introspection.

Acknowledgments

Our extended discussion of these issues appeared in a recent textbook chapter (http://www.nobaproject.com/) [15].

Appendix A. Supplementary data

A PDF of the article with the movie of the illusion embedded can be found, in the online version, at http://dx.doi.org/10.1016/j.tics.2014.05.012. The movie is from http://www.michaelbach.de/ot/mot-mib/ with permission.

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1364-6613/
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Three lines of research are promising for understanding these mechanisms. First, new methods are being developed for precisely measuring neural correlates of conscious and unconscious processing.

Second, multidisciplinary efforts are being made to integrate analyses of behavior, introspection, physiological constraints, and computational requirements (e.g., efficiency, stability, and adaptability), which will facilitate coherent theoretical frameworks to explicate the operation of and interplay between conscious and unconscious processing.

Third, methods to train expertise in introspection are being investigated in research contexts, some inspired by the long history of meditation practices [4,5]. This development is critical because when it comes to research on conscious experiences, our own perspective is not something to dissolve, but rather something to understand in itself.

We share the optimism that Block and colleagues expressed [1]. It is clear that recent progress has provided new insights into neural mechanisms relevant for consciousness. However, an even better metric of the fruitfulness of these approaches is the extent to which new horizons have been opened for empirically testing proposals about consciousness and its neural underpinnings. In this sense, the record of research in this field leaves little doubt that consciousness is a valid topic for scientific inquiry.

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