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Towards a true neural stance on consciousness

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Consciousness is traditionally defined in mental or psychological terms. In trying to find its neural basis, introspective or behavioral observations are considered the gold standard, to which neural measures should be fitted. I argue that this poses serious problems for understanding the mind–brain relationship. To solve these problems, neural and behavioral measures should be put on an equal footing. I illustrate this by an example from visual neuroscience, in which both neural and behavioral arguments converge towards a coherent scientific definition of visual consciousness. However, to accept this definition, we need to let go of our intuitive or psychological notions of conscious experience and let the neuroscience arguments have their way. Only by moving our notion of mind towards that of brain can progress be made.

Introduction

Consciousness is a multifaceted and complex phenomenon, encompassing functions such as language, attention and control. Its most enigmatic aspect, however, is that of conscious experience [1]. Why do some processes in the brain evoke conscious experiences, but others do not? The question is still far beyond our reach, but neuroscience is expected to provide an answer by finding the neural correlate of consciousness (NCC) [2]. Experiments to find the NCC invariably involve some manipulation of consciousness, induced experimentally [3] or accidentally, as in lesion patients. Choices are plentiful (Table 1). However, the intended presence or absence of conscious experience always has to be probed behaviorally, and that is where trouble begins.

This is best illustrated with a classic example. Split-brain patients (Table 1) can always report objects presented in the right half field of vision. But when objects are presented to the left, the patients say not to see them, simply because these are processed by the isolated right hemisphere, which has no capacity for language and speech. However, many patients can draw these unseen objects, select them from a row of other objects, match them to words, or perform other (simple) cognitive operations, as long as the behavior is executed by the left hand, which is connected to the right hemisphere [4,5].

Here is the crucial question: Are these patients *seeing* the objects in the left half field? They say not, and they know best, don't they? Consequently, we might conclude that the right hemisphere is not part of the NCC for visual experience. But can you draw something without seeing it? And isn't selection an expression of recognition and attention? Isn't it unlikely that the right hemisphere cannot sustain conscious experience, simply because it cannot 'talk'? This would argue for *not* excluding the right hemisphere from the NCC. Note that nothing intrinsic to the behavioral experiments provides arguments for or against either conclusion. It all depends on preconceived notions about the role of language in consciousness, about which much has been written but little concluded.

The example highlights two notorious difficulties in gauging conscious experience from the third- (or even first-) person perspective. The first is that some choice has to be made as to what behavioral measures 'count' as evidence for the subject having conscious experience (e.g. drawing versus talk) (Figure 1). The second is that in such heterophenomenological observations conscious experience is easily conflated with cognitive functions that are necessary for the report (in this case language).

This problem has grave consequences for the search for the NCC. Many similar examples exist, in which various, if not all, parts of the brain have been included or excluded from the NCC, entirely depending on the measure of conscious experience, or the notion of consciousness that is started with [6,7] (Table 1). This not only poses a problem for finding the 'true' NCC; more serious is that, in this way, neuroscience will hardly fulfill its promise to get rid of the 'tedium of philosophers perpetually disagreeing with each other' [8].

To find a way out, I think we have to go beyond finding 'neural correlates of', and let the arguments from neuroscience have a true say in the matter. To illustrate this, I first identify the problems of treating visual experience as an entirely mental or psychological concept. I then show how a more coherent scientific definition of conscious visual experience emerges, when both behavioral and neural findings, combined with theoretical concepts, are put on an equal footing. This will, however, entail a view on consciousness that is moving away from our traditional or introspective notions. But this is the only way towards progress.

From neural activation to visual experience

A basic assumption of consciousness research is that when a subject is presented with a visual stimulus it is either seen or not seen. What happens in the brain when a stimulus is shown, and can we establish when conscious experience emerges from the neural activity it causes?

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When a new image hits the retina, it is processed through successive levels of visual cortex, by means of feedforward connections, working at an astonishing speed. Each level takes only 10 ms of processing, so that in about 100–150 ms the whole brain 'knows' about the new image before our eyes, and potential motor responses are prepared. From the very first action potentials that are fired, neurons exhibit complex tuning properties such as selectivity for motion, depth, colour or shape, and even respond selectively to faces. Thus, the *feedforward sweep*

Table 1. Conflating conscious experience with other cognitive functions[a]

Phenomenon	Brief description of phenomenon, and conscious (C) versus unconscious (U) behavior	Lesion and other relevant neural data	Conclusion with respect to the NCC
(a) True manipulations or impairments of conscious experience			
Blindsight [37–39]	Subjects report no conscious experience for the visual field contralateral to the lesion but can guess stimulus properties, localize stimuli, show vegetative or emotional responses, etc. C: Detection U: Localization, guessing, pupil dilation and priming	Lesion to V1. In monkeys, ventral stream areas no longer respond to stimuli whereas parietal cortex (e.g. area MT) still responds. In human subjects, ventral stream areas also respond to stimuli.	NCC sits in the ventral stream, in V1 itself, or is the interaction between V1 and higher visual areas.
Visual agnosia [40]	Failure to recognize objects or their shape, while still seeing basic features. Yet these objects can be localized, picked up or manipulated according to shape. C: Object recognition U: Localization, handling and acting	Results from a lesion to extrastriate and/or ventral stream cortex.	Dorsal stream performs unconscious action towards objects and is not part of the NCC. The NCC sits in the ventral stream cortex.
Backward masking [14,27,36,41, 42]	Presenting a stimulus, shortly followed by another stimulus, the mask, that renders the first stimulus less (or in-) visible. Other varieties exist that might all have different effects. Masked stimuli might cause priming of subsequent choices. C: Detection U: Priming and galvanic skin response (GSR)	Invisible stimuli (d′ = 0) still activate neurons throughout the brain, such as in V1, IT cortex, frontal eye fields or motor cortex, albeit briefly (about as long as the stimulus is physically present). Interrupts delayed signals, probably reflecting feedback or recurrent/re-entrant processing.	The NCC sits nowhere (i.e. is not localizable). The NCC is neural activity passing a certain threshold. The NCC is re-entrant processing.
Dichoptic masking [28]	Presenting stimuli with opposite features (e.g. colors) to the two eyes, so that it becomes invisible in the fused binocular percept. C: Detection U: Localization	Activates the same areas as visible versions of the stimulus, only weaker. Even highly selective areas, such as those responding to faces, are activated.	The NCC is not localizable. Neural activity has to pass a threshold for becoming the NCC.
Transcranial magnetic stimulation (TMS) [11,43–45]	Brief (ms) disruption of neural activity with a magnetic field pulse over the scalp. TMS over the occipital cortex at ~100 ms after stimulus onset disrupts visual awareness. TMS over V1 might still allow unconscious (blindsight) behaviour. C: Detection, discrimination and localization U: Forced choice guessing of stimulus attribute	Shows that activity at ~100ms in V1 (and adjacent early visual areas) is necessary for visual awareness. In higher areas, disruption by TMS is effective at earlier latencies, suggesting that the effect of TMS is mainly due to the disruption of feedback signals to V1.	The NCC is feedback or re-entrant processing.
Binocular rivalry [46–48]	Different stimuli to the two eyes results in suppression of one or the other. Spontaneous alternations of which stimulus is seen, each dominant percept lasting a few seconds. Additional manipulations have shown that the phenomenon is about switching between percepts rather than eye of input. C: Reported dominance of one or the other percept U: Priming by subdominant percept	In monkeys, cells in low-level areas (e.g. V1) respond to the suppressed stimulus, whereas in higher areas (e.g. IT) cells only respond to the conscious percept. In human fMRI studies, there is a strong correlation between neural activity in V1 and perceptual dominance. Switches are accompanied by activation of the frontoparietal network.	Unclear: at first it was thought that high-level areas in the ventral stream are the NCC, but recent fMRI data (and a reanalysis of the early monkey data [48]) cast doubt on this conclusion.

Table 1 (*Continued*)

Phenomenon	Brief description of phenomenon, and conscious (C) versus unconscious (U) behavior	Lesion and other relevant neural data	Conclusion with respect to the NCC
(b) Failures of reportability instead of conscious experience?			
Split brain [4,5]	Failure to verbally report objects that are presented contralateral to the non-language hemisphere (usually the left). But these objects can be drawn, associated with other objects or words, selected from a row of alternative choices or cognitively manipulated. C: Speech U: Drawing, selecting, recognition, pointing out and other simple cognitive manipulations **Manipulation of language instead of consciousness?**	Results from a trans-section of the corpus callosum and commisures that connects the two hemispheres. As a result, what 'happens' to the right hemisphere cannot be verbally reported.	NCC sits in the left hemisphere, the right hemisphere is unconscious.
Neglect or extinction [49–51]	Failure to report or attend to contralateral objects when presented alone (neglect) or in combination with ipsilateral objects (extinction). Yet the unattended objects can induce various forms of priming. C: Selecting, localizing, drawing, recognizing, manipulation U: Priming **Manipulation of attention instead of consciousness?**	Results from a lesion to (occipito- or temporo-) parietal cortex (arteria cerebralis media region). Ventral stream areas still process visual information.	NCC sits in the frontoparietal network that is necessary for attention. V1 and ventral stream are not the NCC.
Change blindness [19,52,53]	Changes between two views of the same scene are not detected, even when as dramatic as changing persons or whole objects. C: Change detection U: Having a hunch that a change occurred **Manipulation of attention instead of consciousness?**	Unseen changes evoke activity in the ventral stream and early visual areas. Seen changes activate the frontoparietal network.	The NCC sits in the frontoparietal network.
Inattentional blindness [17,54]	Subjects cannot report afterwards on objects that were unexpectedly presented outside of the focus of attention. C: Detection, memorization and familiarity upon recall U: Priming and grouping effects **Manipulation of memory instead of consciousness?**	Not remembered stimuli have activated selective areas in the ventral stream, and have evoked re-entrant processing in early visual cortex.	The NCC sits in the frontoparietal network.
Attentional blink [55]	Detection of a target from a stream of stimuli prevents detection of a second target for about half a second (the 'blink' period). C: Detection and identification U: Priming **Manipulation of attention instead of consciousness?**	Early visual cortex (V1) and ventral stream areas are still activated by non-detected targets. Frontoparietal activation is absent.	The NCC sits in the frontoparietal network.

[a]In blindsight, resulting from a lesion to V1, subjects can point at visual stimuli, or guess their shape, color or motion direction. However, subjects verbally deny any conscious experience, nor can they detect the stimuli (i.e. discriminate presence or absence). Detection and talk carry more weight for the presence of conscious experience than localization or guessing (Figure 1), and therefore blindsight is considered the classical example of visually guided behavior in the absence of conscious experience, even in monkeys [37].

Why should we 'trust' these patients, when they say they have no visual experience, even though part of their behavior suggests otherwise? One reason is that the unseen stimuli never spontaneously induce behavior, even after extensive training (although this does happen in monkeys); blindsight capacities only become evident in forced laboratory settings. A second important argument is that no manipulation is capable of restoring, in the lesioned field, the normal vision that the same blindsight patient reports to experience in the intact visual field. The information is and remains completely inaccessible.

This is radically different in other conditions or manipulations. For example, when attention is focused on a particular stream of information, this will often result in other events going unnoticed, or being forgotten, as is observed in phenomena such as inattentional blindness [17], change blindness [19] or the attentional blink [55]. However, in those cases, important events, such as hearing one's name, might capture attention regardless. In other words, the unattended information is not inaccessible, it is just not currently accessed [7]. Whether there is conscious experience in such cases is therefore an open question [7,13]. It could be that experience is present, yet cannot be reported because of the absence of attention.

The table provides a list of manipulations and neuropsychological conditions, and conclusions that have been drawn with respect to the nature or locus of the NCC. A division is made between manipulations where it is arguable whether conscious experience is manipulated instead of some other cognitive function (b) and cases where such arguments would not hold (a). References are not meant to be exhaustive but only give hints for further search on the topic.

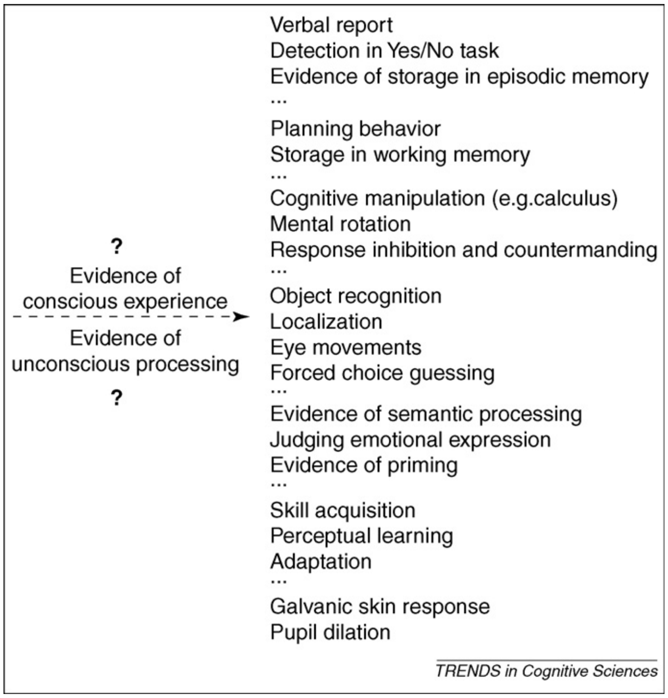

Figure 1. How to measure conscious experience? How can we tell whether a visual stimulus is consciously perceived? Countless behavioral measures are possible, some of which seem more reliable than others. I compiled a list by asking a group of cognitive psychologists to rank measurements in order of the 'weight' these carry as evidence for the subject having a conscious experience. Why do some measures end up higher than others? To a large extent, this reflects ideas about the nature of consciousness that have accumulated over years of psychological research and philosophical debate. The problem lies not in the extreme ends of the scale. But where should we draw the line between behavioral measures signaling conscious versus unconscious processing? In searching for the NCC, behavioral measures that in one study are taken as evidence of conscious experience are taken as measures of unconscious processing in others. Consider the localization and handling of objects. In blindsight and visual agnosia, these are taken as reflecting unconscious processing of objects that cannot be consciously detected or recognized [37,40]. In neglect and extinction [49], however, the failure of patients to look at contralateral objects and manipulate them is taken to imply that these objects are not reaching consciousness. Consequently, opposite conclusions have been drawn from these categories of patients with respect to the locus of the NCC (Table 1).

enables a rapid extraction of complex and meaningful features from the visual scene, and lays down potential motor responses to act on the incoming information [9] (Figure 2a).

Are we conscious of the features extracted by the feedforward sweep? Do we *see* a face when a face-selective neuron becomes active? It seems not. Many studies, in both humans and monkeys, indicate that no matter what area of the brain is reached by the feedforward sweep, this in itself is not producing (reportable) conscious experience. What seems necessary for conscious experience is that neurons in visual areas engage in so-called recurrent (or re-entrant or resonant) processing [9–11] (Figure 2b,c), where high- and low-level areas interact. This would enable the widespread exchange of information between areas processing different attributes of the visual scene, and thus support perceptual grouping [12]. In addition, when recurrent interactions span the entire sensorimotor hierarchy, or involve the frontoparietal areas, potential motor responses could modify the visual responses, which would form the neural equivalent of task set, attention, etc. [7,10].

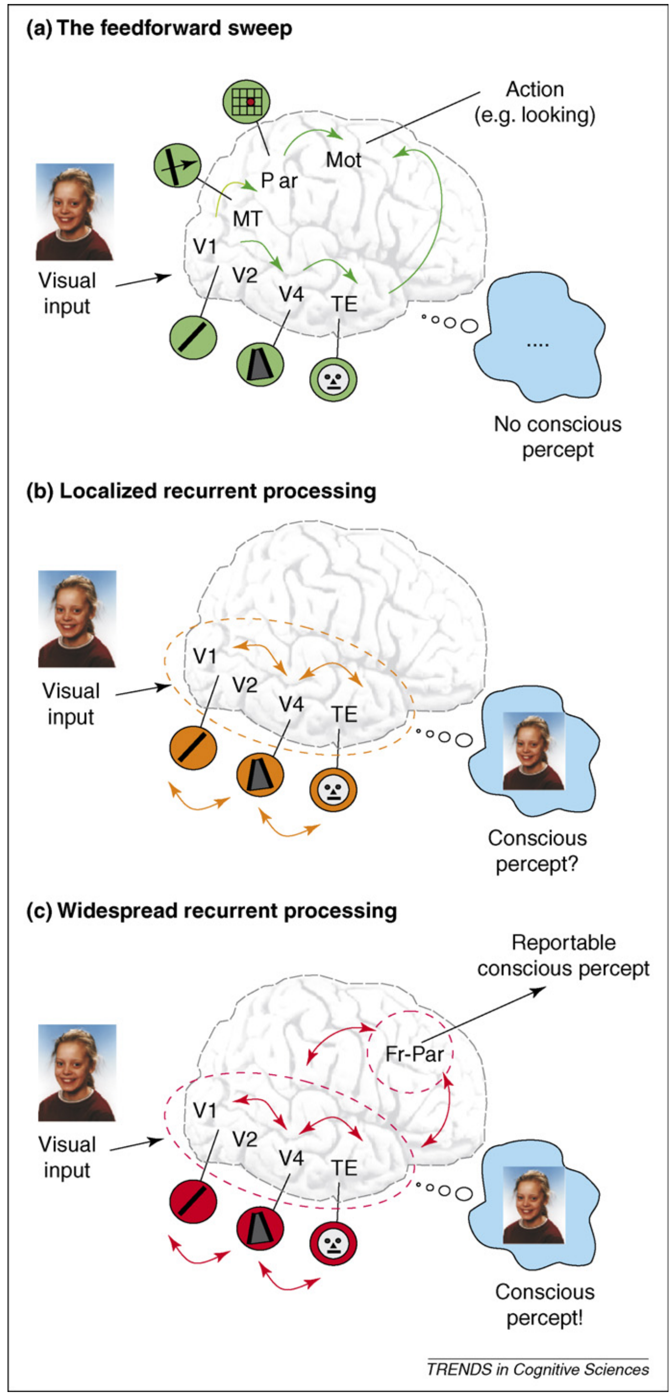

Figure 2. Feedforward sweep and recurrent processing. **(a)** The 'feedforward sweep', the rapid transfer of visual information through the visual cortex and towards motor areas producing a (potential) response. Within several milliseconds each area extracts information about shape, color, motion, position, objects and faces (see icons). Processing by the feedforward sweep is not, however, accompanied by conscious experience of the visual input. **(b)** Recurrent processing enables the exchange of information between higher and lower areas, and within areas, by means of horizontal and feedback connections. Is recurrent processing between visual areas sufficient for a conscious visual percept? **(c)** Reportable conscious experience is present when the visual recurrent core extends towards areas in executive space, such as the frontoparietal network (Fr-Par), or language areas [9,10].

That recurrent processing (RP) is necessary for conscious experience [9,10] is a view that is now being increasingly embraced [7,13,14], although challenging, but entirely empirical, questions remain (Box 1). These are not, however, the topic of discussion here.

Box 1. Outstanding questions

- What is the crucial aspect of recurrent processing that is necessary for conscious experience? Recurrent interactions invariably go along with prolonged activation of high-level neurons, and it has been shown, for example, that the duration of activation of face-selective cells correlates strongly with visibility of masked faces [36]. Can conscious experience be sustained on the basis of such high-level activations alone, even in the absence of recurrency? This could be answered by interrupting feedback signals to V1 (for example with transcranial magnetic stimulation, TMS), while at the same time recording from face-selective inferior temporal (IT) cells.
- Why would recurrent processing give rise to conscious experience? This so-called 'hard problem' [1] is difficult to answer at this point. However, looking at the neural and molecular mechanisms that sustain recurrent processing, such as the activation of NMDA-type receptors [29,34], combined with theoretical notions about the importance of recurrent processing [32] might open up venues towards a deeper understanding of consciousness.
- If indeed there is conscious experience (in the neural sense) in cases such as inattentional blindness, change blindness or attentional blink, and possibly even in neuropsychological conditions such as extinction or split brain, what is the nature of such experiences? For example, does it allow subjects to learn from these experiences? Would this support controversial issues such as speed-reading, eidetic memory or recall under hypnosis?

An impossible question?

Much more challenging is another question: is recurrency in itself sufficient for conscious experience? Do we see a face *as soon as* face-selective and lower-level cells engage in recurrent interactions (Figure 2b)? At first sight, this seems easy to answer. Any instance of RP in the absence of reportable awareness would falsify the idea. Super *et al.* [15] showed that recurrent interactions, recorded in V1 of the awake monkey, are necessary for the animal reporting the presence of texture defined figures. However, raising the decision criterion of the monkey, simply by increasing the number of catch trials, dissociates RP from the behavioral response. Then, recurrent signals are also present when the monkey fails to report a figure percept. Another study (Figure 3) showed the presence of RP signals, while human subjects were in a state of inattentional blindness (IB) towards the objects inducing these signals. During IB, RP remained localized to visual areas. Objects were only reported when the signals showed more widespread interactions, possibly involving the frontoparietal network [16].

Does this falsify the thesis that RP is sufficient for conscious experience? Note the similarity with the split-brain conundrum outlined above. It could be argued that the only reason why the monkey fails to report its conscious experience is that we have raised the number of catch trials, and hence the monkey's decision criterion. Only if we equate conscious experience to the outcome of his decision process (or to the eye movement signaling that outcome) can we fully 'trust' its report.

Similarly, does IB really show the absence of conscious experience? Simply put, subjects just do not remember stimuli presented outside their focus of attention [17]. Storage in episodic or working memory is taken as the measure of conscious experience. Unless consciousness and episodic memory are taken as the same thing, it cannot be excluded that the subject was conscious of the stimulus at the moment of its presentation, yet simply forgot about it [18]. This might sound strange, but experiments on the related phenomenon of change blindness [19] show that unattended objects are represented in the mind in a fleeting, yet reportable, representation that disappears as soon as a new scene is presented or the eyes move to a new location [20].

So again, we find ourselves in a labyrinth of arguments. We could take the subject's report at face value and conclude that RP is insufficient for conscious experience. In such a view, cognitive functions involved in conscious report (attention, working memory and language) are part and parcel of consciousness, whereas other functions are unconscious. But then why not simply study these cognitive functions, and abandon studying consciousness

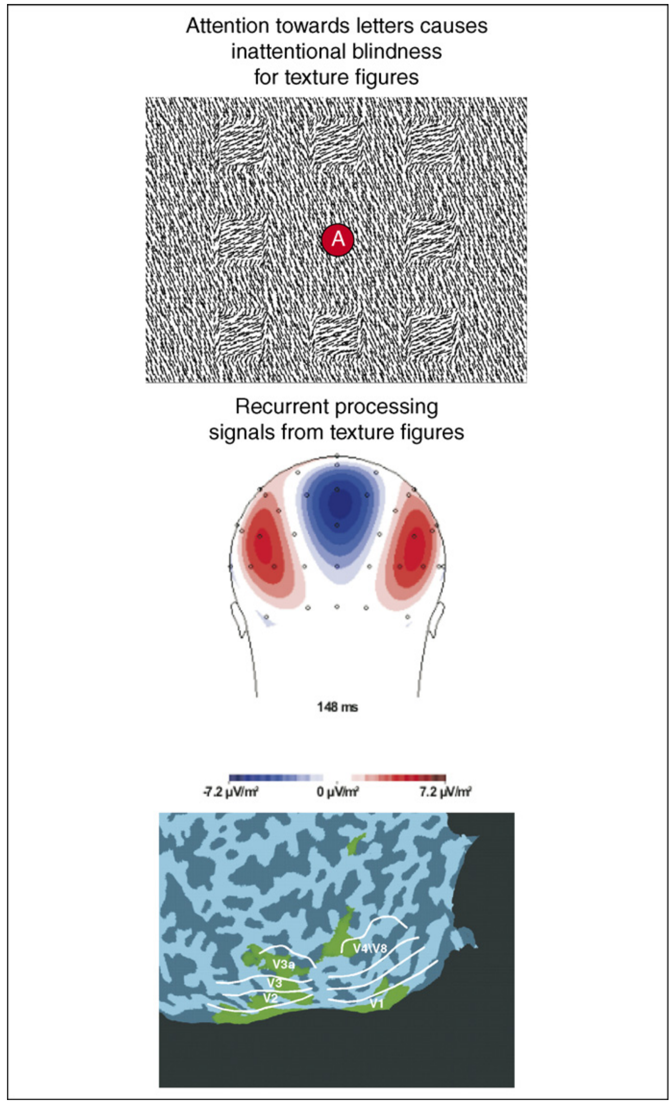

Figure 3. Recurrent processing during inattentional blindness. Results from a modified version of the experiment performed by Scholte *et al.* [16]. Subjects were instructed to focus attention on a foveally presented stream of black and white letters, and report the occurrence of white vowels. All letters were presented in textured backgrounds, but at some occasions, additional square figures were present in the surround of the fixation spot (as shown in the upper panel). Afterwards, 50% of subject reported not to have seen these square figures, that is they suffered from inattentional blindness or amnesia. Regardless, brain signals recorded with EEG (middle), MEG [16] and fMRI (lower) revealed that the unseen textured figures evoked recurrent interactions between several visual areas.

and the NCC? Moreover, any sharp division between conscious and unconscious cognitive functions will again be arguable, often resorting to taste rather than scientific argument.

The alternative view would hold that conscious experience is only done full justice when viewed as independent from other cognitive functions. Evidence for this idea is found in the many instances of attention [21], object recognition [22], learning [23], semantic processing [24] and even reasoning [25] without conscious reportability of what was learned, recognized, etc. In that view, RP could be seen as the NCC of visual experience, even when not reported. But how to verify conscious experience without any cognitive function interfering? This even applies to introspective reports. You cannot *know* whether you have a conscious experience without resorting to cognitive functions such as attention, memory or inner speech. This problem lies at the heart of the seemingly unsolvable debate on the existence of 'non-accessible' or phenomenal (P-) consciousness [26].

Recently, the problem was recognized in the context of a global workspace theory of consciousness [7]. It was proposed to let such states of localized RP, not involving the frontoparietal networks associated with attention and reportability, fall in a category between the fully unconscious and the fully conscious, called the 'preconscious', where visual information is 'visible yet not seen'. This hardly solves the issue of whether there is any phenomenally conscious aspect to such a state, and the authors acknowledge that whether there is conscious experience in such a state 'does not seem to be...a scientifically addressable question' [7].

Taking the neuroscience argument seriously

This is where I diverge. The question seems not addressable *because* we do not let all scientific arguments have their way, and treat conscious experience as something that can only be observed behaviorally or introspectively. We could find a solution, when we let neuroscience go beyond 'finding neural correlates of'. Consciousness should not only be inferred from behavioral measures, to which neural measurements are subordinate. Both measures should be on an equal footing.

There is no need to doubt the presence of conscious experience when a subject reports a clearly visible event, nor its absence in cases such as blindsight or deeply masked stimuli (Table 1a). In those cases, arguments about the conflation of conscious experience with other cognitive functions do not hold up. It is the middle ground where additional, neural arguments become of value (Table 1b). Let's see what such arguments would bring in answering the seemingly unanswerable: Is there conscious experience when RP is limited to visual areas, as seems to be the case in inattentional or change blindness, attentional blink, and possibly in conditions such as extinction and split brain?

A starting point would be the observation that when RP encompasses visual as well as frontoparietal areas, a reportable conscious experience ensues [7,10]. This begs the obvious question as to what the essential neural ingredient of this state is *for the generation of conscious experience*. Is it the involvement of the frontoparietal network, as global workspace theory suggests, or is it the recurrency? A neural argument against the former would be that activation of cortical neurons *per se*, even activation of frontoparietal neurons, is insufficient for conscious experience, as is shown by various masking experiments [14,27–29]. This would promote the recurrency as being the most important ingredient.

Another neural argument would come from considering that RP is fundamentally different from feedforward processing. RP creates a condition that satisfies the Hebb rule, where the pre- and postsynaptic neurons are active simultaneously. This will trigger the activation of synaptic plasticity processes, which are the neural basis of learning and memory [30]. In other words, stimuli that evoke RP change your brain, while stimuli that evoke only feedforward activation have no lasting impact. It would be difficult to see why the involvement of the frontoparietal network would make such a difference (after all, it is all neurons firing action potentials, whether they are in the back or front of the head). Cases of learning during inattention provide evidence for the point [23].

Theoretical arguments further stress the importance of recurrency. Tononi argues that consciousness is the capacity of a system to integrate information [31,32]. This capacity depends crucially on the system's propensity to form a 'dynamic core', or complex, characterized by the strong mutual interactions among its elements, as well as by its complexity, that is the large number of possible states it can achieve. Because of its connectivity, the corticothalamic network has the capacity to form dynamic cores of high complexity, whereas other brain structures, such as the cerebellum or basal ganglia, do not [32]. Therefore, also in this account, recurrent interactions between cortical neurons are the crucial feature of consciousness, not which cortical regions sustain these interactions, which is only relevant for the type of conscious experience that results. Importantly, the proposal allows for multiple complexes to exist at the same time [32]. In the IB experiment (Figure 3), one complex could therefore represent the attended stream of letters, while another would represent the not-reported objects in the background. By definition, both would be conscious representations.

According to such empirical and theoretical arguments, RP is the key neural ingredient of consciousness. We could even *define* consciousness as recurrent processing [10,33]. This could shed an entirely different light on the matter of whether there is conscious phenomenal experience in states of inattention, split brain or extinction. The matter would now become a *scientific* debate, where evidence from behavioral observations is weighed against the evidence from neural measurements. If recurrent interactions of sufficient strength are demonstrated, it can be argued that the 'inattentional', 'preconscious' or 'not reported' still have the key neural signatures of what would otherwise be called conscious processing.

What do we lose, what do we gain...

Letting arguments from neuroscience override our intuitive and introspective notion of consciousness seems strange. After all, consciousness is almost synonymous to private access and personal feeling. So what is the benefit of adopting a more neural stance on consciousness? At first sight, we seem to lose explanatory power. There would be instances of (neurally defined) conscious processing that are not evident from behavioral measures or introspection (Figure 3). It is not unusual in science, however, to move away from intuitive notions. We have grown accustomed to the fact that, despite appearances, dolphins should be called mammals and sodium a metal. There are solid scientific arguments to do so. Are there such arguments in the case of RP and consciousness?

As noted above, RP is crucial for the induction of synaptic plasticity. A first advantage of adopting a neural definition of the conscious–unconscious dichotomy would therefore be that we have a much more fundamental understanding of what consciousness is or does: we need consciousness to learn. This insight might also open up ways towards an understanding of consciousness at the cellular or molecular level, as synaptic plasticity is associated with specific synapses and receptor types [30,34]. Although the 'hard problem' [1] is not solved by this in itself, it holds better promises of doing so than traditional NCC approaches.

A second advantage is that we would be able to dissociate consciousness from other cognitive functions, such as attention, working memory and reportability, which is a prerequisite for using the term at all. Elsewhere [10,33], I have shown how, from the neural perspective, attention and consciousness can be orthogonally defined as entirely separate neural processes. When other cognitive functions are neurally defined as well, we do not lose explanatory power at all by adopting the neural stance. It can be easily understood why there is no reportability of conscious experience in the case of IB, split brain, neglect and other conditions; in all these cases there are *other* cognitive functions than consciousness (neurally defined) that are manipulated, which is causing the failure of reportability.

Third, the neural dichotomy between 'recurrent = conscious' and 'feedforward = unconscious' yields testable predictions for behavioral experiments. If indeed all recurrent processes share the feature of phenomenality *and* the inclination to induce synaptic plasticity, it can be predicted that learning will follow the phenomenal aspects of stimuli (e.g. color), rather than their physical features (e.g. wavelength), even when what is learned is not reportable.

Finally, an obvious advantage would be that we can measure the presence or absence of consciousness without resorting to behavioral measures, enabling us to settle long-standing debates about the presence or absence of consciousness in neural disease, locked-in syndrome, coma, anesthesia, or animals. In fact, in these cases, neural measures are our only resort.

...by moving our notion of mind towards that of brain?

I have tried to point out that, by adopting a partly neural stance on consciousness, seemingly unsolvable issues in consciousness research can be solved. I do not claim that the neural definition of consciousness that I propose [10,33] is ultimately correct. It is the approach that I advocate. Alternative neural definitions might be proposed [7,35]. Our task should be to evaluate each of these on its scientific merits and capability to deal with all the phenomena concerning consciousness and cognition. We should be prepared, however, to abandon our traditional ideas about what consciousness is, and let the neuroscience argument have its way. Otherwise, it is useless to do any neuroscience on the topic at all.

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