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# Binding and the Phenomenal Unity of Consciousness

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The binding problem is frequently discussed in consciousness research. However, it is by no means clear what the problem is supposed to be and how exactly it relates to consciousness. In the present paper the nature of the binding problem is clarified by distinguishing between different formulations of the problem. Some of them make no mention of consciousness, whereas others are directly related to aspects of phenomenal experience. Certain formulations of the binding problem are closely connected to the classical philosophical problem of the unity of consciousness and the currently fashionable search for the neural correlates of consciousness. Nonetheless, only a part of the current empirical research on binding is directly relevant to the study of consciousness. The main message of the present paper is that the science of consciousness needs to establish a clear theoretical view of the relation between binding and consciousness and to encourage further empirical work that builds on such a theoretical foundation. © 1999 Academic Press

## WHAT IS THE BINDING PROBLEM AND HOW IS IT RELATED TO CONSCIOUSNESS?

It seems to be taken for granted that, first, everybody knows exactly what we are talking about when we discuss the binding problem and second, that this problem is bound to be relevant for the study of consciousness. However, if we take a look at the recent literature in which the problem has been discussed, interesting ambiguities and disagreements emerge, revealing that what we are dealing with here is not a single problem at all, but a set of related problems that should be distinguished from each other and analyzed at different levels of description.

How is the binding problem actually characterized in the literature? Here are some quotations selected for consideration:

> There is, next, what is commonly referred to as the binding problem, a critical problem for visual physiology. The problem is that of determining that it is the same (or a different) stimulus which is activating different cells in a given visual area or in different visual areas. (Zeki, 1992, p. 321)

In the quotation above, the problem is depicted along the following lines: How do external physical objects, as physically unified entities, get mapped in the brain as neural entities, when input processing seems to segregate the activity originated in the same physical object across a multitude of neural feature maps? Binding is

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thus seen as a problem of finding the mechanisms which map the ‘‘objective’’ physical entities in the external world into corresponding internal neural entities in the brain. The key issue here is to reveal the ways in which neurons ‘‘code’’ or ‘‘respond to’’ the features of external physical objects. Note that in this formulation of the binding problem, *no reference is made to consciousness.* Binding is rather seen as any process or mechanism that in some sense recovers the unity of the stimulus object; a unity objectively existing out there in the physical stimulus. I call this conception of binding *stimulus-related binding.* It refers to *any* neural processing that represents *stimulus* unity, regardless of whether the activity in question is conscious or unconscious.

A slighty but significantly different idea of binding can be seen in the following characterization of binding:

> Current knowledge from neuroanatomy and neurophysiology of the primate nervous system indicates unequivocally that any entity or event that we normally perceive through multiple sensory modalities must engage geographically separate sensory modality structures of the central nervous system. . . . The experience of reality, however, both in ongoing perception as well as in recall, is not parcellated at all. The normal experience we have of entities and events is coherent and ‘‘in-register,’’ both spatially and temporally. Features are bound in entities, and entities are bound in events. How the brain achieves such a remarkable integration starting with the fragments that it has to work with is a critical question. I call it the *binding problem.* (Damasio, 1989, p. 29)

Here Damasio quite clearly refers to our *experience* of reality, entities and events, which normally is unified. How the brain brings about *that* unity—the unity of consciousness—is regarded as constituting the binding problem. I call this conception of binding *consciousness-related binding:* How are internal subjective percepts, as phenomenally unified entities, constructed by the brain as neural entities, considering that the neural mechanisms necessary for creating different phenomenal contents are distributed all around the cortex? Consciousness-related binding is thus seen as a problem of finding the neural mechanisms which map the subjective phenomenal experiences in consciousness onto corresponding neural entities in the brain.

Once the idea of consciousness-related binding is formulated, it becomes immediately clear that it is closely associated with two central problems in consciousness research. The first concerns the unity of phenomenal consciousness. The contents of phenomenal consciousness are unified into one coherent whole, containing a unified ‘‘me’’ in the center of one unified perceptual world, full of coherent objects. How should we describe and explain such experiential unity? The second problem of relevance here concerns the neural correlates of consciousness. If we are looking for an explanation to the unity of consciousness by postulating underlying neural mechanisms, these neural mechanisms surely qualify for being direct neural correlates of unified phenomenal states.

Consciousness-related and stimulus-related binding can be dissociated from each other. A paradigm case of stimulus-related binding is realized in experiments in which neural synchronization occurs in response to visually presented real objects in anesthetized animals. Since the animals are totally unconscious, it is quite obvious that whatever the neural events are that map global stimulus properties to the brain, they cannot reflect the unity of phenomenal consciousness, for there is no conscious state there that could realize phenomenal unity. Therefore such a neural state cannot be a direct neural correlate of consciousness, for obviously the neural state can occur without any conscious states present in the brain.

A paradigm case of consciousness-related binding is one in which we have a unified perceptual state in the absence of a unified external stimulus. We then have an illusory or hallucinatory unity in consciousness. Illusory coherence can be realized, for example, by looking at random-dot stereograms. The monocular stimulus is just a seemingly haphazard collection of black dots on a flat white surface, but by applying binocular fusion it is possible to see a unified three-dimensional object that seems astonishingly real. A very natural source of unified but hallucinatory contents of consciousness is dreaming: our dreams are full of perceived objects and characters that for the most part appear just as unified as our waking percepts do. Somehow the brain realizes these unified percepts without any online access to corresponding external stimulus objects.

Stimulus-related binding and consciousness-related binding do not *necessarily* have anything to do with each other, though sometimes (as in veridical waking perception) consciousness-related binding may at the same time also be stimulus-related. As far as I can tell, there is only one author in the literature, namely, John R. Smythies, who clearly distinguishes these two types of binding:

> There are two quite different binding problems, which we can call BP1 and BP2. BP1 asks ‘‘How is the representation of information built up in the neural networks that there is one single object ‘out there’ and not a mere collection of separate shapes, colours and movements?’’ . . . This presupposes an underlying mechanism that locates the right colour in the right shape and keeps both moving together. . . . There do not seem to be any difficulties about this question (Smythies, 1994a, p. 54). BP2 asks ‘‘How do the brain mechanisms actually construct the phenomenal object?,’’ which is another matter altogether. (Smythies, 1994b, p. 321)

When it comes to consciousness-related binding—and to consciousness studies—the binding problem can be depicted as follows: How are internal subjective percepts, as phenomenally unified entities, constructed by the brain as neurally unique entities, considering that the neural mechanisms necessary for creating different phenomenal contents (e.g., color, movement, vision, audition, touch) are distributed all around the cortex. Consciousness-related binding is thus seen as a problem of finding the neural mechanisms which map the unified contents in phenomenal consciousness to corresponding neural entites in the brain.

## BINDING AND THE DIFFERENT LEVELS OF DESCRIPTION

Distinguishing stimulus-related and consciousness-related binding is not enough, for other confusions, concerning the nature of the binding problem remain. Just to illustrate this, consider the following exchange between Crick and Koch and Searle:

> . . . It is highly reasonable to assume that seeing any one object often involves neurons in many different visual areas. The problem of how these neurons temporarily become active as a unit is often described as ‘‘the binding problem.’’ (Crick & Koch, 1990, p. 269)

Searle criticizes this formulation of the binding problem:

> Crick says the binding problem is ‘‘the problem of how these neurons temporarily become active as a unit.’’ But that is not the binding problem; rather, it is one possible approach to solving the binding problem. (Searle, 1997, p. 33)

Crick and Koch propose that binding involves a large number of anatomically separated neurons and that the binding problem simply is the problem of finding out the neural mechanisms that can transiently unify such an ensemble of neurons. Why doesn't Searle accept this characterization? When Searle discusses binding, he seems to have in mind the unity of experience, of consciousness—phenomenal unity. *That* is the kind of unity that the science of consciousness should primarily be interested in—not the unity of neural assemblies per se.

I propose that in order to avoid confusion we should distinguish different levels of description at which binding and unity can be conceptualized. In the widest sense, binding refers to the ability of the brain to produce coherent, integrated representations of the world and harmonious, functional sequences of behavior, although information about the external world is received in multiple forms through numerous sensory channels, and initially processed in a multitude of separate pathways and areas that reside in a fragmented fashion throughout the brain. Binding and integration, thus conceived, take place at many different levels of description and organization. I shall distinguish the following levels from each other: (1) The phenomenal level (the contents of phenomenal consciousness). (2) The level of neural mechanisms. (3) The level of cognitive mechanisms.

The conceptual frameworks with which integration is described at these distinct levels are dissimilar to each other. At the phenomenal level, we need a systematic account of the contents of (perceptual) consciousness and of the ways in which such contents can be understood as being composed of simpler features and integrated in coherent phenomenal representations. We need to ask: In what sense are the contents of consciousness normally integrated? In which ways can the contents of consciousness become disintegrated in exceptional circumstances? Thus, for consciousness studies, the binding problem is primarily *the problem of integration at the phenomenal level of organization in the mind-brain.* This integration can only be depicted at the phenomenal level of description, i.e., by describing actual contents of consciousness.

By contrast, for neuroscience the binding problem is *the problem of integration of single neuron activity to functional neuronal groups and assemblies.* It is closely related to another fundamental problem in neuroscience, namely, the nature of the ‘‘neural code,’’ or the basic functional principle of neural activity in the brain, and the following difficult question: At which level of organization (the single neuron, the patterns of activity in neural populations, or the temporal synchronicity of neural activity) does the nervous system organize itself into functionally and behaviorally relevant units?

From the point of view of cognitive science and cognitive neuropsychology the binding problem shows itself in yet another form. According to the modularity hypothesis (Fodor, 1983; Ellis & Young, 1988), the input processing of perceptual information is handled by a multitude of isolated, specialized, mandatory, fast, nonconscious, neurologically specific modules. In this kind of cognitive architecture, the cognitive binding problem can be formulated as follows: *How does our cognitive system unify the results of the multitude of distributed modular processing, to create unified representations of objects for perception, recognition and memory?*

When it comes to consciousness research, binding refers to the integration of phenomenal contents into unified phenomenal wholes. The unity of consciousness is here regarded as the truly problematic phenomenon; the cognitive and neural level descriptions are treated as descriptions of the (possible) *mechanisms* of phenomenal binding. Cognitive and neural level descriptions are of interest to consciousness studies only insofar as they can be, directly or indirectly, related to integration at the phenomenal level, i.e., insofar as they can be regarded as the possible underlying explanatory mechanisms of phenomenal binding. In other words, if a type of (phenomenal) unity or binding as described at the phenomenal level can be related to binding at the lower cognitive or neural levels of description, then those lower levels are of significance for understanding consciousness. In such cases we may even hope for *explanatory shifts* to take place from the higher, phenomenally unified levels to the lower neurocognitive levels at which we should, correspondingly, be able to show how the unity at the higher level arises from integrative mechanisms at the lower levels.

## DIFFERENT TYPES OF BINDING

Phenomenal unity does not denote a single type of integration—on the contrary, there are many different ways in which our phenomenal content is unified. Let us for a moment consider our typical phenomenal experience: what are the contents of consciousness usually like for us? Practically every moment when we are conscious at all, we feel a *sense of presence* in a spatially extended world, and we can feel our own body (i.e., the phenomenal body-image) as a spatial object in the center of this world. Every distinct part of the subjective visuospatial field surrounding us is interpretable as a meaningful object (or a part of a meaningful object), involving multiple sensory features and having a distinct shape, color, identity, and location in the subjective perceptual field. Thomas Metzinger (1995) characterizes the unity of this subjective reality by pointing out the strong experience that I am *one* person in *one* world: there is an all-pervading holistic character of subjective reality, the property of wholeness or phenomenal coherence. He calls the experientially present whole or subjectively experienced reality ‘‘a phenomenal Holon.’’ I take this as referring to the experience of one single perceptual and behavioral space which contains all the multitude of different kinds of perceptual objects that in some sense are currently present for the subject.

What kind of binding mechanisms are needed to construct such a remarkable unity? We should not assume that there is just one simple type of binding tying all experiential contents together. On the contrary, there may be numerous independent mechanisms. How does the brain construct a perceptual object which we simply and directly experience as a specific object in a specific location? Consider a natural scene around you, a meadow full of grass and flowers, surrounded by trees and bushes, for example. You see a swallowtail flying by. How does your brain build this model of the world with all the amazing colorfulness, detail, and animation? How is a phenomenal representation of a single object generated? First of all, the light reflected from the object triggers the appropriate receptive fields of a multitude of different cells in the visual system. How do these individual cells ‘‘know’’ that they are responding to the same object; that somehow their responses ‘‘belong together’’? There are lots of factors that influence the *spatial grouping* of visual features. Many of them are stated in the classical Gestalt laws of perceptual organization (e.g., proximity, similarity, good continuation, common fate, closure). When the spatial grouping of simple visual sensations fails, we end up with a condition such as apperceptive agnosia (Farah, 1990). Patients suffering from it enjoy elementary visual sensations, but do not seem to perceive objects as solid forms or surfaces. They are so helpless in adapting themselves to their visual environment that they may appear blind to outside observers. They may infer the identity of an object by using visual sensations of color or texture as cues, but that is an inference, not a visual perception. Thus, patients with apperceptive agnosia undoubtedly have *some* sort of visual phenomenology, but of a peculiarly structureless kind, which does not suffice for being a visual *model of the world.*

Closely connected to spatial grouping is *feature integration* or *property binding* (Treisman, 1996), for the shape and contour of an object may be determined by several distinct elementary features such as color, texture, luminance, or coherent motion. In natural objects (and unlike black-and-white line drawings of objects) we typically have many such features integrated together in the object that we visually perceive—just think of your conscious visual perception representing the swallowtail flying from flower to flower. Property binding can fail when insufficient focal attention is paid to objects in the visual field. The failures can lead to illusory conjunctions of properties, which can be experimentally induced in the laboratory by presenting stimuli with different feature combinations, but not allowing enough time for serial focused attention to bind the properties appropriately. The subjects report seeing such combinations of color and form that never existed among the stimuli—the brain incorrectly ‘‘glues’’ a color and a form together in visual awareness (Treisman & Schmidt, 1982).

The features involved in property binding seem to be quite independent of each other, for it is possible to permanently lose a specific phenomenal feature from one’s phenomenal model of the world. The most dramatic cases are those of complete cerebral achromatopsia, in which the patient’s model of the world loses all chromatic color. A famous case of this sort is vividly described by Oliver Sacks:

> It had gradually come upon him, during this time, that it was not merely colour perception and colour imagery that he lacked, but something deeper and difficult to define. He knew all about colour, externally, intellectually, but he had lost the remembrance, the inner knowledge, of it that had been part of his very being. . . . It was as if his past, his chromatic past, had been taken away, as if the brain’s knowledge of colour had been totally excised, leaving no trace, no inner evidence of its existence behind. (Sacks, 1995, p. 10)

> But black and white for him was a reality, all around him, 360 degrees, solid and three-dimensional, twenty-four hours a day. . . . neither ‘‘grey’’ nor ‘‘leaden’’ could begin to convey what his world was actually like. It was not ‘‘grey’’ that he experienced, he said, but perceptual qualities for which ordinary experience, ordinary language, had no equivalent. (Sacks, 1995, p. 8)

A complete object may also be composed of several distinct parts, the wings and the body of the swallowtail, for example, which must be correctly combined in visual awareness in order to make sense of the object—this is *part binding* (Treisman, 1996). In some cases of prosopagnosia, binding the parts of a face into a structured whole fails; a patient may explain that ‘‘I can see the eyes, nose and mouth quite clearly, but they just don’t add up’’ (Pallis, 1955, p. 219, quoted in Ellis & Young, 1988, p. 90).

A remarkable feature of objects in natural scenes is their immediate meaningfulness. As we serially scan our surroundings and shift our attention from one location to the next, not only do the elementary features of objects become bound into coherent entities, but instantaneously we are able to categorize the attended object as some kind of meaningful entity. Thus, each separate object activates a coherent network of semantic knowledge in the brain. We not only see a coherent bundle of features, we see it *as* a reprsentative of a specific category of objects and are able to immediately access an enormous amount of information about that kind of object. Every meaningful bundle of features thus opens a specific ‘‘window’’ to semantic knowledge. This binding is not a form of *visual* binding, since it does not concern the structure of visual awareness, and objects represented nonvisually (e.g., spoken words) can open up these semantic windows as well. However, this type of binding, which I call *semantic-conceptual binding*, certainly is an essential ingredient of our phenomenal consciousness, since it allows us to experience the world around us as familiar and meaningful. Semantic-conceptual binding is deficient in patients with semantic dementia or other disorders of semantic knowledge (Saffran & Schwartz, 1994). Although such a patient typically has no visual problems, a visual shape or a coherent bundle of visual features fails to open up the corresponding specific semantic window. The world and its objects lose their meaningfulness and distinctive character as objects representative of specific kinds. Consequently objects can be categorized by such patients only in the most general terms (‘‘an animal’’). Dreaming is a nonpathological condition in which object identity sometimes remains peculiarly vague. Objects, persons, and places in dreams may fail to open up coherent semantic windows, and thus the precise character of a phenomenal element in visual awareness may remain very unclear for the dreamer. The vagueness of dream contents is one of the main forms of what has been called the bizarreness of dreams (Hobson, 1988; Revonsuo & Salmivalli, 1995).

In the preceding examples we have mostly been considering the kinds of binding that are required in object vision and recognition. However, there is more to our conscious experience than just visual objects: there is also the *space* around us in which we feel that our body and all the perceived objects are located. We not only immediately see the shape and identity of an object, we are also aware of its position in relation to our own body and to other objects in the scene. This is *location binding* (Treisman, 1996). This ability is so profoundly built into the brain’s model of the world that we may fail to appreciate its very existence. Patients with dorsal simultanagnosia or Balint’s syndrome, however, have lost this ability, although they can still see single objects as coherent and meaningful bundles of features (Farah, 1990): i.e., feature binding, part binding, and semantic-conceptual binding are still functional. Thus, a patient with dorsal simultanagnosia might well be able to see a butterfly and recognize it as a swallowtail, but he cannot point at it or describe where it is located in space. For such a patient, subjectively experienced space seems to collapse down to the space within the currently attended object (Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997).

Finally, the model of the world is not presented to us as a still photograph with stagnated objects at specific locations. Instead, it is an *animated* world full of motion and change across temporal intervals. Thus, objects need to preserve their identity through time, although they may change position or be otherwise transformed. This may be called *serial* or *event binding.* Again, there are interesting cases in which serial binding breaks down. Visual motion blindness or akinetopsia is a rare disorder in which the visual world comes out as if in successive still photographs (Zihl, von Cramon, & Mai, 1983; Zeki, 1991). Although objects preserve their identity through time, they cannot be seen as *moving* objects, which makes it very difficult to estimate the dynamic properties of objects. Another kind of failure in serial binding appears in dreaming, where it is not uncommon to find objects or persons that suddenly appear, disappear, or change identity.

In sum, phenomenal experience is unified. It is unified globally, to form one coherent phenomenal whole (the unity of consciousness), and it is unified locally, so that objects are experienced as coherent sets of phenomenal features located in specific spatial locations. The different kinds of binding and disintegration at the phenomenal level suggest that normally the contents of consciousness are the result of a great variety of binding mechanisms that, to some extent at least, function independently of each other. The brain's phenomenal online model of the world is a stunningly complex system. We first need to be able to describe it systematically in order to be able to propose specific explanatory mechanisms for it. The binding problem is a good place to start: charting the varieties of consciousness-related binding and revealing the underlying mechanisms will increase our understanding of the integration and disintegration of subjective experience, thus exposing the phenomenal unity of consciousness for empirically based scientific research.

## BINDING AND CONSCIOUSNESS: IS SYNCHRONIZATION THE DIRECT NEURAL CORRELATE OF VISUAL AWARENESS?

When we evaluate empirical work on the binding problem and consciousness, it is useful to keep in mind the numerous distinctions, levels, and types of binding discussed above. If a study reports stimulus-related synchronization as a response to the global properties of a simple visual stimulus in an anesthetized animal, not much can be said about the relation of such findings to the unity of consciousness, although the results may be of great value from the point of view of neural mechanisms of stimulus-related binding. If binding is studied in the context of computational neural network simulations, we have no reason to believe that phenomenal consciousness is involved, although the results may be of significance for the computational modeling of network behaviors. If, however, fully conscious human subjects are used in a functional brain imaging experiment in which illusory or hallucinatory perceptual unity is realized, then we have at least some hope of capturing the neural correlates of unified phenomenal states.

Engel, Fries, Konig, Brecht, and Singer (this issue) propose that synchronization is a necessary condition for neural activity to contribute to awareness, whereas the firing rate or amplitude of feature coding cells does not directly reflect selection to further processing. The claim is based on animal studies of the neural correlates of subjective perception during binocular rivalry. This is a significant conclusion, for it seems to imply that synchronization establishes a functionally relevant level of organization of neural activity above the level of the basic firing rates. Here we also encounter the deepest theoretical problem in neuroscience: we have no idea what the correct level of analysis is, because there is no universally accepted theory of how the brain codes information. Searle (1997, p. 198) has called this disgraceful lack of theory ''the dirty secret of contemporary neuroscience.'' Therefore also, the picture of the neural correlates of visual awareness that we get from studies on binocular rivalry is very much dependent on the level of organization we are observing: the modulation of firing rate (Logothetis' group) or the modulation of synchronicity (Singer's group). Which (if either) of these levels should be regarded as the more relevant level of analysis when we attempt to understand the level of visual awareness?

We should remember the general point that when searching for the appropriate explanatory levels of a phenomenon in a complex biological system, it is crucial that we first successfully identify the level(s) of organization in the system at which the phenomenon of interest is actually realized. In the history of biology, deep disagreements have emerged concerning the crucial level of organization at which a certain phenomenon resides and at which level of description the theoretical explanations should be constructed. For example, biological respiration was argued by some researchers to be realized and explained at the level of specific organs (lungs), by others at the level of tissues (blood), and by yet others at the level of the individual cell (Bechtel & Richardson, 1993). The individual cell turned out to be the correct level of organization. The problem of identifying the mechanisms of cellular respiration within the cell was not easy either; finally, the complex internal structure of the mitochondrion—a specific structural component within the cell—was established as critical for the chemical reactions involved (Bechtel & Richardson, 1992). From this historical point of view, it is interesting that we already have several competing hypotheses about the level of organization at which the direct neural correlates of consciousness should be expected to be found, reaching all the way from the quantum level to the level of the whole brain (see, e.g., the collection of papers in Hameroff, Kaszniak, & Scott, 1998).

The hypothesis that the single cell is the most relevant level of organization for consciousness implies that we should try to identify certain specific types of neurons, distinguishable from other types by their basic structure and function. The anatomy, electrophysiology, pharmacology, and other properties of the ''neuronal correlates of consciousness—neurons''—are expected to be different than those of other neurons in the brain (this strategy is advocated by, e.g., Crick & Koch, 1998). The neural network hypothesis suggests that phenomena realized at the level of single cells are not the crucial ones, but that features realized at the level of complex interaction of huge numbers of cells is the relevant level of organization. Synchronization is one such higher level feature: the activity of a single neuron can be synchronized only in relation to the activity of other neurons.

The account proposed by the Singer group does not deny the relevance of single cell rate coding or specific structural/functional properties (‘‘synchronizing connections,’’ Roelfsema, Engel, König, & Singer, 1996) to the higher level cell assemblies, but the patterns of activity directly underlying perceptual gestalts can be realized only at the level of the cell assembly. In the final analysis, it may turn out that the levels of organization are much more complex than the simple division to single cell properties vs. network properties suggests. The cells constituting the neural correlates of consciousness may, in some basic way, be different from other neuron types at the single cell level, and just because of that, large assemblies of such cells may be able to realize exceptional features at higher levels of organization.

In addition to finding the proper levels of analysis, there is another methodological problem. Most of the empirical evidence is coming from animal studies. In the worst cases, the animals are anesthetized and the researchers can look only for stimulus-related binding. Even if binding was consciousness-related, as is necessarily the case when looking at the neural correlates of the currently dominating stimulus in binocular rivalry, we can claim no access to animal phenomenology. Thus, the science of consciousness cannot solely rely on animal experiments, because then the most crucial level of organization for consciousness studies, the phenomenal level, remains seriously inaccessible. In the field of consciousness research, an ideal study uses human observers so that we can be sure what the phenomenology of the subject is in the experimental situation. Human studies of course prevent us from using invasive microelectrodes, but noninvasive methods such as MEG or scalp EEG can detect large-scale neural synchronization, for they are sensitive to the summation of activity from a huge number of neurons. Thus, if 40-Hz responses can be detected at such a level, they have to be generated by a large population of neurons firing synchronously at around the same frequency. There are a few studies that have taken this approach.

Lutzenberger, Pulvermueller, Elbert, and Birbaumer (1995) showed coherently moving bars to human subjects and detected increased 40-Hz power in scalp EEG over the occipital lobe in response to the stimulation. Although this result is nicely in concert with previous findings in animals, it is primarily evidence for stimulus-related synchronization, not necessarily consciousness-related. In order to reveal consciousness-related synchronization, one should present ambiguous stimuli which do not contain physical coherence, but which the human perceptual system can nevertheless construe as involving global coherence. In this spirit Tallon, Bertrand, Bouchet, and Pernier (1995) and Tallon-Baudry, Bertrand, Delpuech, and Pernier (1996) showed real and illusory coherent triangles to subjects and detected a 40-Hz EEG component with widespread topography and maximum amplitude at posterior electrodes around 300 ms poststimulus to both types of stimuli. Unfortunately, it is not entirely clear whether this response reflected binding or target detection, for their target stimulus closely resembled a real triangle. Tallon-Baudry, Bertrand, Delpuech, and Pernier (1997) reported similar findings when they used the famous hidden picture of a dalmatian as the stimulus. They suggest that this 40-Hz response reflects assembly coding activated either from the bottom up or from the top down (or perhaps both).

We have recently reported an experiment on binocular fusion in human vision that may to some extent illuminate the issue of the relation between synchronicity and binding in visual awareness (Revonsuo, Wilenius-Emet, Kuusela, & Lehto, 1997). The hypothesis that 40-Hz synchronization is associated with the binding of visual percepts into coherent wholes was tested by measuring scalp EEG (20 electrodes) in a task in which the subjects ($N = 8$) perceived the same stimulus (a random dot autostereogram) in one condition as an incoherent collection of random dots and in another condition as a coherent, symmetrical, three-dimensional gestalt. Continuous viewing of the same stimulus in the incoherent vs. coherent condition was not associated with significant differences in 40-Hz synchronization (quantified as relative change in 36- to 44-Hz band power between the two conditions). Thus, although there is a radical *phenomenological* difference in the content of visual awareness between these two stable views of the stimulus, no corresponding difference in 40-Hz band power was detected. The same was true of lower frequency bands at 8–13 and 13–20 Hz.

Next, we tested the hypothesis concerning whether the online perceptual *construction* of the coherent (but illusory) gestalt is accompanied by transient 40-Hz synchronization. The subjects free-fused the random-dot stereogram and pushed a button as soon as they saw the three-dimensional gestalt clearly. In the control condition, they fused a stimulus from which no unified percept emerged. Increase in 40-Hz power (relative to the control condition) was observed at occipital and right parieto-temporal electrode sites in a time window 500–300 ms before visual awareness of the coherent percept was reported. No corresponding changes in band power were observed at the lower frequencies we analyzed (8–13 and 13–20 Hz). The 40-Hz synchronization thus seems to participate in the construction of the unified percept, but not in the continuous viewing of the same stimulus once it has been constructed and persists in visual awareness.

This result suggests that 40-Hz synchronization does *not* directly correlate with the *content* of visual awareness per se, but with the *construction* immediately preceding the emergence of such content into visual awareness. This lends support to the thesis advanced by Engel et al. that temporal binding is a prerequisite for the access of information to phenomenal consciousness.

It can be argued that the continuous viewing condition with a coherent and incoherent view of the same stereogram did not in fact involve any binding problem, at least if binding is regarded as an ongoing process leading from a disorganized to an organized state, rather than the resulting stable, organized state *itself.* Although the two stable views of the stimulus did not require any further binding, they still were radically different from each other at the level of visual phenomenology. Whatever the direct neural correlate of visual awareness is, it simply *has to* reflect this phenomenological difference; there has to be some sort of neural difference corresponding to the difference at the phenomenal level. Our results suggest that 40-Hz synchronization does not reflect such a difference, so 40-Hz synchronization does not seem to be the direct neural correlate of the content of phenomenal visual awareness. The continuous stable view of the symmetrical gestalt in visual awareness does not supervene on continuous 40-Hz synchronization (at least not on continuous synchronization higher than in the control condition), although the state transition from an incoherent to a coherent view seems to do so.

Consequently, the really interesting question can now be formulated in the following way: if transient synchronization constructs organized, unified, and relatively stable neural states, *what is the nature of those states* (in neural terms) after their construction is completed? This of course is the core issue in explaining the phenomenal unity of consciousness, for the states in question are likely to directly underlie the phenomenal unity of visual awareness.

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