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What is wrong with the no-report paradigm and how to fix it

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Abstract

Is consciousness based in prefrontal circuits involved in cognitive processes like thought, reasoning, and memory or, alternatively, is it based in sensory areas in the back of the neocortex? The no-report paradigm has been crucial to this debate because it aims to separate the neural basis of the cognitive processes underlying post-perceptual decision and report from the neural basis of conscious perception itself. However, the no-report paradigm is problematic because, even in the absence of report, subjects might engage in post-perceptual cognitive processing. Therefore, to isolate the neural basis of consciousness, a no-cognition paradigm is needed. Here, I describe a no-cognition approach to binocular rivalry and outline how this approach can help resolve debates about the neural basis of consciousness.

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What is the Neural Basis of Consciousness?

In recent years the scientific study of **consciousness** (see Glossary) has focused on finding the **neural basis of consciousness** in the brain. There are many theories of the neural basis of consciousness, but in broad strokes theories tend to divide on whether consciousness is rooted in the 'front' or the 'back' of the brain. More specifically, they divide on whether perceptual consciousness is based in the neural circuits in prefrontal and parietal cortex that are devoted to cognitive processes like thinking, reasoning, evaluating, reporting, deciding, memory or, alternatively, whether perceptual consciousness is based in areas in occipital and temporal cortex that are devoted to sensory processing.

Garnering firm support for cognitive theories versus sensory (or non-cognitivist) theories has proven methodologically challenging. However, it is widely held that the **no-report paradigm** [1] can help adjudicate between these two perspectives. The logic of the no-report paradigm is as follows: suppose we seek to isolate the neural basis of consciously seeing, say, a face. Clearly, we would want to contrast brain activations in which a subject is consciously seeing a face with brain activations in which the subject is not consciously seeing a face. However, we typically only know whether subjects are consciously seeing a face via their own self-reports. So it may seem that the neural basis of consciousness of a face will inevitably be entangled with the neural basis of the post-perceptual cognitive processes underlying judging what the stimulus is, maintaining that answer in working memory and deciding what response to make [1, 2]. The no-report paradigm is supposed to be a way of finessing this problem by using reports to find and validate indicators of conscious perception that work in the absence of reports.

Although the no-report paradigm has been influential in recent years, it has a fatal flaw: eliminating reports does not eliminate post-perceptual cognitive processes if the subjects are thinking and reasoning about the stimulus. We must find a way to replace the "no-report" paradigm with a "no-post-perceptual-cognition" paradigm. In this article, I suggest a path forward.

The Opposing Sides

As indicated above, theories tend to divide on whether consciousness is rooted in the ‘front’ or the ‘back’ of the brain. However, ‘front' and 'back' are vague terms, and both sides regard parts of the parietal cortex as part of the neural basis of consciousness. The real neocortex-location issue is whether certain regions (not all) in front of the central sulcus are necessary for perceptual consciousness. **Prefrontalists** say yes, advocates of the "back" say no. Prefrontalists emphasize dorsolateral, medial prefrontal, anterior cingulate and orbitofrontal regions of prefrontal cortex. But front/back is really a surrogate for the more fundamental issue of whether consciousness is cognitive or whether it is perceptual (in a wide sense that includes imagery, dreaming and hallucination). It is because activations in some areas of prefrontal cortex appear to be necessary for cognitive function that it looms so large in these debates. (What is meant by **cognition** here is thought-based mentality, notably reasoning, deciding, evaluating, reporting and working memory.) Advocates of the "back of the head" view of consciousness can allow that if thought has its own kind of phenomenal consciousness, it might be based in cognitive regions of prefrontal cortex. The important difference between cognitivist and non-cognitivist views is that the non-cognitivist says perceptual consciousness does not require cognitive processing.

This ‘front of the head’ versus ‘back of the head’ debate maps onto popular theories of consciousness. Prefrontalists are represented by the **global workspace theory** [3]) and the **higher order theory** [4, 5] of consciousness. According to the global workspace theory, sensory activations compete among themselves, with dominant neural coalitions in sensory areas triggering workspace neurons in frontal and parietal cortex, forming an active reverberating network that makes sensory information available to reasoning, reporting, decision-making and other cognitive processes. According to higher order theories of consciousness, what makes a **perception** conscious is that there is an accompanying cognitive state about the perception. Meanwhile, the back of the head accounts, are represented by the **integrated information theory** [6] and the **recurrent processing theory** [7] of consciousness. According to the Integrated Information Theory, a system is conscious to the extent that it is both differentiated and integrated. According to the recurrent processing account, consciousness is a matter of the formation of feedback loops with certain neural properties.

This debate between advocates of the front and the back is widely recognized to be the focus of current thinking about consciousness. Indeeed, the Templeton World Charity Foundation is funding an "adversarial collaboration" to—among other things-- resolve the issue between advocates of the front and back of the neocortex [8]. The frontalists recently published a manifesto [9] in *Science*, arguing that if we are to make conscious machines, we should base them on the computations that underlie human consciousness. The computations they describe are those advocated by global workspace and higher order theorists.

One caution about the neuroscientific work to be presented: it is all correlational and of course one must be careful in inferring anything about the neural basis of mentality from correlational studies. Causal studies in which the effects of brain interventions (e.g. lesions, electrical stimulation, optogenetics) are assessed are better to the extent that they are available.

Using Binocular Rivalry to Study Consciousness

Figures at end of ms., after Glossary

Unusual phenomena often provide the test cases for theories. One such phenomenon is **binocular rivalry**, in which different stimuli presented to the two eyes results in oscillating perceptions. Binocular rivalry has played a central role in consciousness research because it allows researchers to hold a stimulus constant while the contents of consciousness shift. **Error! Reference source not found.** (panel A) depicts the brain of a subject who is wearing red/green glasses and is viewing a red house superimposed on a green face. One eye receives a face stimulus and the other a house stimulus. The conscious perception—diagrammed in panel B—is not a combined image but rather conscious alternation, with all or most of the visual field filled by the conscious perception of either a face or a house, alternating every few seconds. Subjects are aware of intermediate mixtures between a face and house, but the experience consists mainly of one percept or the other, with more complete dominance if the stimuli are small. Subjects can influence which of the percepts dominates, but inevitably the non-dominant percept takes over.

Why does this alternation occur? According to the prevailing account of rivalry, pools of neurons representing each of the incompatible stimuli inhibit one another [10]. In the presence of neural noise, one pool wins temporarily. Then that pool is weakened by adaptation and the other pool representing the other alternative takes over. Because of the impact of neural noise, the time of the transitions cannot be predicted on the basis of past transitions. Binocular rivalry occurs in many animals, including fruit flies, and can occur in humans with invisible stimuli, showing that binocular rivalry is not intrinsically a conscious process [11].

Decoding Transitions vs Decoding Contents

When subjects in a binocular rivalry experiment are scanned during the rivalrous perceptions, what is found is neural correlates of the transitions between one percept and the other in visual areas in the back of the head and stronger differential activations in cognitive areas in the prefrontal cortex and parietal cortex. These experiments also isolated the neural basis of the perceptual contents themselves, activations in the fusiform face area in the case of face perceptions and activations in the parahippocampal place area in the case of house perceptions. Both areas are in the back of the head. A conclusion often drawn from these early rivalry experiments, especially on the basis of the stronger frontal correlations with transitions, was that although the neural basis of the contents of perception such as face content or house content was in the back of the head, what makes those contents conscious was based in the front of the head [12].

It is important to distinguish the neural basis of transitions in rivalry from the neural basis of the contents of the rivalrous states themselves [13]. Of course what we are interested in is mainly the neural basis of the contents, but the neural basis of the transitions can be important in finding the neural basis of the contents. If there is no prefrontal difference linked to perceptual transitions, then we can conclude that the perceptual contents cannot be prefrontal. However, if there is a prefrontal difference linked to perceptual transitions, it is much less clear what to conclude. The prefrontal difference might be due to differences in preconscious stages of processing [14] or to differential attention to the changing stimulus, to elevation of arousal due to a transition, or to motor control of response keys rather than changes in the content of conscious perception. What is crucial in deciding between theories of consciousness is a method of separating out those transition-related changes that are systematically related to perceptual contents.

The methodology of many binocular rivalry experiments is designed only to detect transitions, not the contents themselves. Often studies of binocular rivalry involve comparisons between binocular shifts and what is called "replay"-- real changes between say a face stimulus and a house stimulus with the same contents. fMRI always involves subtraction of one condition from another. (See part C of Figure 1.) In this paradigm, transition-related activations during replay are subtracted from transition-related activations during rivalry. Since both cases are supposed to involve the same conscious perceptual contents, in principle what is left after the subtraction is correlates of the transitions without any information about the perceptual contents themselves

No-Report Paradigm in Binocular Rivalry

The stronger frontal correlations with transitions in binocular rivalry may have been due to the fact that the cognitive processes involved in deciding what to report involve frontal activations. That idea motivated the "no report" paradigm. If one eye is shown a grating moving to the left and the other eye is shown a grating moving to the right, the subject is aware of leftward motion (usually in the whole visual field), then rightward motion, then leftward motion, etc. Using a method first discovered in [15], a recent study used a characteristic eye movement called **optokinetic nystagmus** that correlates with the perceived direction of motion as indexed by the subjects' reports [16]. Smooth pursuit to the left plus sharp jerky motions to the right correlate with reports of conscious perception of the grating as moving leftward and there is a corresponding association for rightward motion. In binocular rivalry, there are always brief intermediate states that involve patches of percepts of the two stimuli and aspects of the nystagmus correlated with that too.

Once the researchers had verified the accuracy of nystagmus using self-reports, they put subjects in the scanner. However, once in the scanner, subjects were not given any task and they were not asked for any reports. The researchers then looked at differences in brain activations when nystagmus indicated a perceptual transition. Of course, subjects could testify *after* the experiment was over that their percepts were alternating as usual. The transitions mainly reflected differences in perceptual areas in the back and middle of the head. The article summarizes: “Importantly, when observers passively experienced rivalry without reporting perceptual alternations, a different picture [that is, different from what happens with report] emerged." That different picture is that differential neural activity in prefrontal areas was minor compared to activity in temporal and parietal regions. They "conclude that prefrontal areas are associated with active report and introspection …” [16, p. 1738]. And the article’s title reflects this emphasis: “Binocular Rivalry: Frontal Activity Relates to Introspection and Action But Not to Perception”.

This result led to a flurry of controversy [17, 18] in which different types of experiments seemed to differ in whether they showed prefrontal differences in perceptual transitions in a paradigm closely related to binocular rivalry. These results presented serious challenges to the conclusion just described. In particular, prefrontal reflections of perceptual contents were decoded in a no-report experiment with monkeys using electrophysiological methods (electrodes inserted in cortical regions) that are known to be more sensitive to neural activations than the fMRI used in the result mentioned in the last paragraph [17]. Impressively, these results used monkeys that had not been trained on a discrimination task, ruling out covert decision-making that would have been expected to make a prefrontal difference (personal communication from Theofanis Panagiotaropoulos, the corresponding author of [17].). Later work in the same lab has been devoted to recording from grids of micro-electrodes ("Utah" arrays) placed in the prefrontal cortex of monkeys in a binocular rivalry setup with gratings in different directions, suggesting decoding of direction from prefrontal cortex [19, 20]. In addition, another group was able to decode perceptual contents from prefrontal areas in binocular rivalry [18]. However, this result did not use a no-report paradigm so the prefrontal representation could have been linked to the cognitive processes underlying reporting.

A caution about decoding from prefrontal cortex: because of linkages across the whole brain, it may be possible to "decode" anything from anywhere in the brain if one has sufficiently sensitive detection. The real issue is which regions involve optimal decoding over a wide range of circumstances.

In sum, work using the no-report paradigm has shown that even without reports, both contents and transitions can be decoded from frontal cortex during binocular rivalry. However the no-report paradigm is not dead. It can be modified to avoid the problems just described, as I will argue in the next section.

The Need for a No-Post-Perceptual Cognition Paradigm

Suppose it is confirmed using microelectrode arrays that conscious perceptions (not just transitions) can be decoded from prefrontal cortex in binocular rivalry in a no-report paradigm. Would that result show that prefrontal cortex is part of the neural basis of conscious perception? No, because of the "*bored monkey" problem*. The monkeys in these experiments spend hours looking at gratings going up and down without any task other than **fixating**. If you were in this perceptual situation, you might have some cognitive states—thinking, wondering, questioning, musing, and the like-- concerning the grating moving up when it is moving up and the grating moving down when it is moving down. As a consequence, the micro-electrode arrays could be tapping post-perceptual cognitive processing concerning which way the gratings are moving rather than the perceptions of the gratings themselves. Note that I am not talking about daydreaming or mind-wandering. Those states cannot be controlled and, in any case, would not engender systematic error. The problem is that the monkeys may be undergoing cognitive processes that are systematically aligned with one or another of the rivalrous percepts.

This problem reveals a flaw in the reasoning behind the "no report" paradigm. Eliminating report is only successful in isolating the neural basis of conscious perception if it eliminates post-perceptual cognitive processing such as thought and judgment about the reportable properties that is systematically correlated with one of the perceptual representations. The same problem infects recently rediscovered [21] older versions of the "no-report" paradigm involving humans [22] since nothing was done to prevent subjects from thinking about their alternating percepts.

So, what we really need to do is to replace the "no-report" paradigm with a "no-cognition" paradigm—or better, a "no post-perceptual cognition" paradigm (to avoid begging the question against views that take conscious perception to be cognitive). But this may seem manifestly impossible. When subjects see things, they are free to make perceptual judgments and think about what they see. You can't stop subjects—including monkeys-- from thinking. We seem to be at an impasse.

The No-Post-Perceptual Cognition Paradigm in Action

There is, however, a solution to be found in a recent experiment by Brascamp and colleagues [23]. (To avoid misunderstanding, note that this experiment did not involve nystagmus.) In this study, the authors reasoned that detection of prefrontal transitions in binocular rivalry might have to do with the attraction of attention to perceptual transitions rather than [perceptual transitions per se]. To circumvent this, they designed stimuli for which the transitions would be "inconspicuous", and thus would not draw the subject's attention. The stimuli were randomly moving dots (see Figure 2). Frequently (every 300 ms) there were transitions in which each dot moved in a random direction and the coherence of the dots' motion (the extent to which dots moved together) shifted. In one condition, the dots in the two eyes were of different colors, whereas in the other condition, the dots were of the same color.

The key idea is this: for the condition in which the eyes are shown *different* color dots, subjects noticed the rivalrous change of dominant eye because the color changed. However, for the condition in which the dots were of the *same* color, the subjects were much less likely to notice the change of dominant eye. The explanation is that they had a hard time detecting whether a change was due to a change of dominant eye or to one of the frequent changes in which each dot moves in a different direction. Thus, the conscious changes due to a change in dominant eye were "inconspicuous" and could be expected not to draw attention and not be noticed. (Subjects are generally not aware of which of their eyes is dominating the perception in binocular rivalry.).

Thus, Brascamp, et al. had created a case of binocular rivalry in which the rivalry did not draw attention.

How do we know that the subjects were actually consciously experiencing two different perceptual contents when the different stimuli dominate? It might be said that both stimuli were experienced simply as randomly moving dots with constantly changing motion and coherence patterns. In that case, there would be no conscious difference between one eye dominating and the other eye dominating.

Brascamp, et al.addressed this issue. They were able to confirm, using a number of different methods, that perceptual binocular rivalry was occurring for the same-color patterns in Figure 2--that is, that the two displays triggered different perceptions. One such method involved a separate experiment varying the dot density in the two eyes. Note that at any given moment, the arrays shown to the two eyes differed in the direction of motion of every dot and the extent to which its motion cohered with the motion of other dots. When the two eyes receive different inputs, there are only two alternative perceptual situations: (1) the percept can reflect some kind of combination or merger of the two inputs or (2) the percept can reflect rivalrous alternation of the sort described earlier. See Box 1 for an explanation of the factors that determine merger as opposed to rivalrous alternation. When Brascamp, et al.asked for reports of density, they tended to get responses indicating that the perceived density reflected the number of dots shown to one eye rather than any sort of combination or merger of the two eyes.

This result confirmed that there was little merging in their procedure, thus showing that often subjects must be experiencing real conscious rivalry. They further confirmed conscious rivalry by exploiting known temporal regularities of rivalry. Subjects were consciously experiencing repeated shifting of the patterns, but as noted earlier, they had no way of distinguishing between the transitions that reflected rivalry and those that reflected the regular change of patterns.

Were the rivalrous switches inaccessible or unreportable? No! They were accessible but mostly not accessed. The rivalrous switches were (mostly) indistinguishable from the switches that were happening every 300 ms, so the rivalrous switches did not stand out and were not noticed and so did not produce differential cognitive states. Brascamp, et al.say (p. 1674): "Based on the sensitivity index, *d*', detection of switches in the same color condition could not be distinguished from chance, demonstrating just how inconspicuous these switches are." That is, the subjects were (approximately) at chance on distinguishing the rivalrous switches from the run-of-the-mill switches that were happening all the time. All switches—rivalrous and non-rivalrous-- were noticeable, accessible and reportable, but the subjects mostly could not pick out the rivalrous switches from the ones that were happening all the time.

So, what did Brascamp, et al.find? Using fMRI, they could detect prefrontal differences in the case of different color dots but not in the case when the dots were of the same color. As they say, prefrontal differences in activation for the inconspicuously different stimuli were "altogether undetectable in our procedure". They conclude that "when viewing a conflicting or ambiguous stimulus, a switch in perception may arise in the visual system, but noticing the change may rely on brain regions dedicated to behavioral responses" [23, p. 1677]. The upshot is that it may be *noticing* that brings in prefrontally represented cognitive concepts—the perceptions in cases that do not draw attention are based in perceptual areas in the back and middle of the head.

Note that although Brascamp, et al.justified the method of inconspicuous switches by appealing to the need to avoid attracting attention to the switches, there is another benefit of the procedure, and one that is the focus here: this method avoids the systematic change of cognitive states like thought and judgment that can accompany rivalrous changes. If one first thinks that one is seeing a grating moving upward and then thinks that one is seeing a grating moving downward, then that change of thought, based in prefrontal cortex, can, if correlated with the percept, seem to indicate a prefrontal change even if prefrontal cortex plays no role in consciousness at all. In precluding such a sequence of events, their methodology is not just a no-report methodology, it is a no-post-perceptual-cognition methodology. The upshot is that in at least one instance of a no-post-perceptual-cognition paradigm, there may be no prefrontal component to conscious change.

Anticipating an Objection

I can imagine an objection being raised that the univariate fMRI used in the study by Brascamp, et al. is not sensitive enough to capture the differences between the two percepts. Case in point, Odegaard, et al. [24] argued that failure to find prefrontal differences with fMRI may miss real effects that would be detected by other means. They mention that ECog recordings in which there is direct intracranial electrophysiological recording in human surgical epileptics (in which the skull is opened and electrode grids are placed on the cortex) showed differential prefrontal activity even when subjects were not required to report the stimulus. Odegaard, et al. are right that ECog may pick up changes missed by fMRI but using patients to test rivalry without doing anything to keep them from thinking about what they are experiencing does not satisfy the point made here that the subjects may be thinking about the perceptual contents even when not required to report on them. Still, the basic point that Odegaard et al. were making does apply to the Brascamp, et al. experiment since the rivalry changes in that experiment, involving only direction and coherence of motion of dots, might require temporal and spatial resolution too fine grained for fMRI. Thus, although the Brascamp, et al. experiment is evidence against prefrontalism, further experiments with ECog could support prefrontalism.

Concluding Remarks

In sum, the "no-report" methodology was an overly simple approach to the methodological problem of isolating the neural basis of consciousness. The real methodological problem is how to distinguish the neural basis of conscious perception from the neural basis of thought, judgment and reasoning. There may be no general solution to this problem, but at least in the case of binocular rivalry a solution may be at hand. I believe that the experiment reported in Brascamp et al. does provide some support for non-cognitive theorists, but the main point of this article is to home in on the methodological issue rather than supporting one side.

BOX 1. Rivalry vs Merger

When different stimuli are presented to the two eyes, in some cases the perceptions merge and in other cases they alternate in dominating the perception. What determines the difference? Figure I shows a masculine and feminine face presented, each to a different eye. If the subject attends to local features or to parts of the faces, such as the eyes, the subject experiences standard binocular rivalry, as indicated in the diagram by "Alternating percepts". Standard binocular rivalry also occurs if the faces are presented upside down. However, if the subjects attend to holistic features such as gender, there is fusion instead of rivalry: the subject sees an androgynous face that blends masculine and feminine features [25].

What determines whether there is rivalry or merger? We can call rivalrous stimuli "incompatible" and merging stimuli "compatible". Mere luminance differences don't contribute to incompatibility so long as the items of different luminance are of the same shape and contrast polarity. (Contrast polarity is a matter of being lighter or darker than the background. Both the 'X' and the 'O' of Figure II are composed of elements that are lighter than the background, so they are the same in contrast polarity.) The items of Figure II are compatible locally because the squares are of the same shape and contrast polarity but differ globally ('X' vs 'O'). All the subjects in [26] experienced fusion of these items rather than rivalry. And other experiments using more complex setups have also reported that holistic differences don't matter if there are no relevant local differences [27].

The explanation of the primacy of the local is that local properties tend to be represented in monocular parts of visual cortex. There is more binocular processing in higher vision where receptive field sizes are much larger than in monocular areas. Binocular rivalry usually depends on monocularly represented features, features that differ in the two eyes, whereas what we naively think of as the contents of perception, e.g. seeing an ‘X’ vs seeing an ‘O’, are represented binocularly, mainly in higher areas.

BOX 2. Rivalry and Predictive Coding

The local nature of binocular rivalry creates difficulties for many theories of perception. For example, the "predictive processing" approach [28] regards perception as a matter of "controlled hallucination" in which hypotheses involving general knowledge of what might be seen confront the data. As mentioned earlier, a commonly used binocular rivalry stimulus is one in which a face is shown to one eye and a house to the other. What the subject experiences is an alternation between a face and house perception, in which each fills the whole visual field for a brief period. Advocates of the predictive processing approach see the issue in terms of conflict between a face hypothesis and a house hypothesis, fed by the general knowledge that nothing is both a face and a house. Andy Clark [29] explains the reasoning, following [30]:

> But why, under such circumstances, do we not simply experience a combined or interwoven image: a kind of house/face mash-up for example? … Such mash-ups do not constitute a viable hypothesis given our more general knowledge about the visual world. For it is part of that general knowledge that, for example, houses and faces do not occupy the same place, at the same scale, at the same time. … This, indeed, may be the deep explanation of the existence of competition between the higher-level hypotheses in the

first place — these hypotheses must compete because the system has learned that 'only one object can exist in the same place at the same time' ....

But as we have seen, apart from high level attention of the sort mentioned in connection with Figure I, general knowledge hypotheses about faces being different from houses and one thing in one place at one time play little role in determining the difference between compatible and incompatible stimuli. The most important determinants are low level local features.

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Glossary

Binocular rivalry. In binocular rivalry, "incompatible" stimuli presented to each eye results in dominance of first one stimulus, then the other, ad infinitum. (What makes stimuli incompatible is described in Box 1.)

Cognition: thought-based mental states and processes, for example, reasoning, deciding, evaluating, reporting and memory. What is especially important to cognition is transitions among propositional states that are based on the contents of those states.

Consciousness: Phenomenal consciousness is what it is like to have an experience. Phenomenal consciousness can be distinguished at least at the conceptual level from access-consciousness: global availability of information. In this article, the term 'consciousness' is restricted to phenomenal consciousness.

Fixation: To fixate a thing or area of space is to point your eyes at it.

Global Workspace theory of Consciousness: According to the global workspace theory, sensory activations compete with one another for dominance. Dominant sensory neural coalitions trigger workspace neurons in frontal and parietal cortex, forming an active reverberating network that makes sensory information available to reasoning, reporting, decision-making and other cognitive processes.

Higher Order Theories of Consciousness: According to higher order theories of consciousness, what makes a perception conscious is that it is accompanied by a cognitive state about the perception. Higher order theories of consciousness differ in whether the higher order state itself has a sensory content that could compete with the first order content or whether the higher order content is more of a pointer with an index of reliability of the first order state.

Information Integration Theory of Consciousness: According to IIT, a system is conscious to the extent that it is differentiated and that its different possible states are integrated with one another. A highly conscious and therefore highly integrated system cannot be decomposed into separate subsystems that are themselves as highly integrated and differentiated. IIT is a theory of what makes a system a conscious subject, whereas the other theories of consciousness are primarily concerned with conscious states of a subject.

Neural basis of consciousness: the minimal neural activity that is sufficient for consciousness. It is possible that there are different neural bases of consciousness in different conscious beings.
Perceptual consciousness: conscious phenomenology involved in perception. What cognitivists and non-cognitivists disagree about is whether perceptual consciousness requires prefrontal cortex activations. Non-cognitivists allow that the non-perceptual phenomenology of thought might be rooted in prefrontal cortex.

No-report paradigm. In a no-report paradigm, subjects are assigned no task of discriminating one stimulus from another. In no-report paradigms, reports can be used to calibrate other methods of indexing consciousness, such as the OKN reported in the text.

Optokinetic nystagmus (OKN). During a conscious percept of a moving grating, a subject's eyes move slowly in the direction of motion and then sharply back in the opposite direction
Perception: sensory objective representation of the environment

Prefrontalists: Those who hold that activation of certain circuits in front of the central sulcus are necessary for perceptual consciousness, notably dorsolateral, medial prefrontal, anterior cingulate and orbitofrontal regions. Prefrontalists subscribe to either the global workspace theory or to the higher order theory of consciousness.

Recurrent Activation Theory of Consciousness: The content of consciousness depends on which circuits are activated but what makes those contents conscious is reverberating feedback to early sensory areas that satisfies certain spatial and temporal constraints, especially if it involves burst firing of neurons.

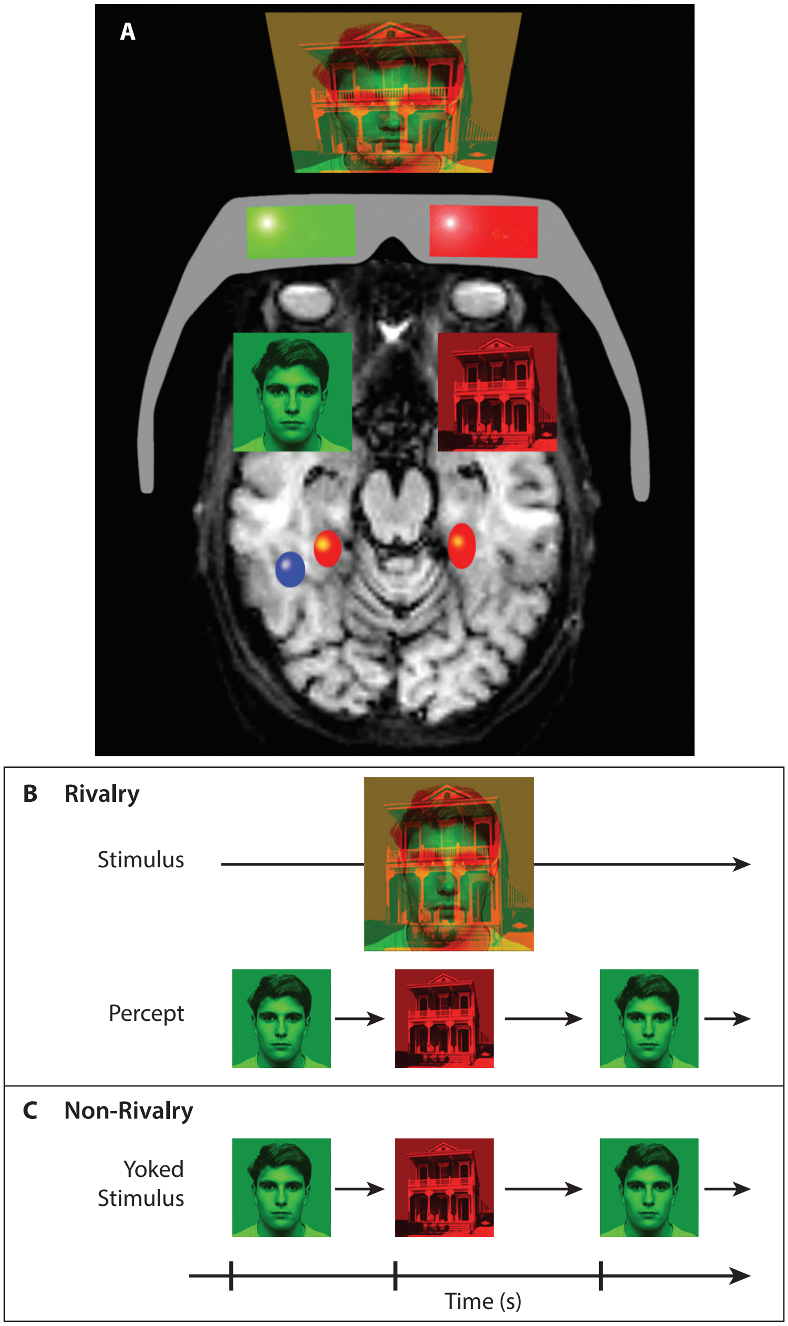

Figure 1

Figure 1. Binocular Rivalry. (A) shows the brain of a person looking through red and green glasses at a superimposed picture of a face and a house. (B) shows the percept, first of a face, then a house, then a face. (C) shows the replay that in many experiments is compared with rivalry I am grateful to Frank Tong for this diagram. See also [31].

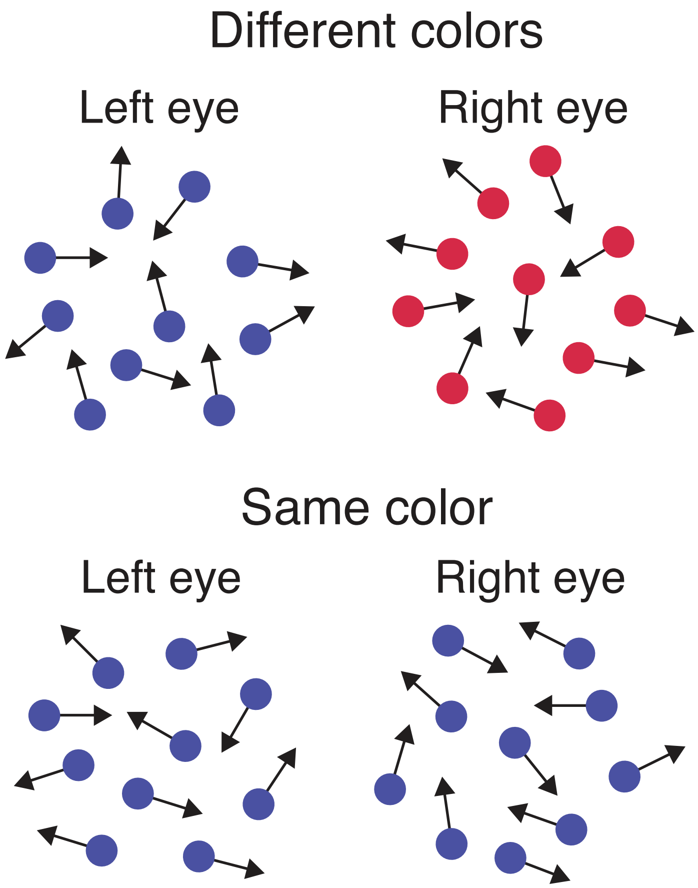

Figure 2

Figure 2. Inconspicuous Binocular Rivalry. Quasi-random motion stimuli used in binocular rivalry experiments by [23]. The alternation between the blue and red dots at the top is very noticeable but the alternation of the same-color dots is not because the dot pattern is ever-changing. Thanks to Jan Brascamp for this figure.

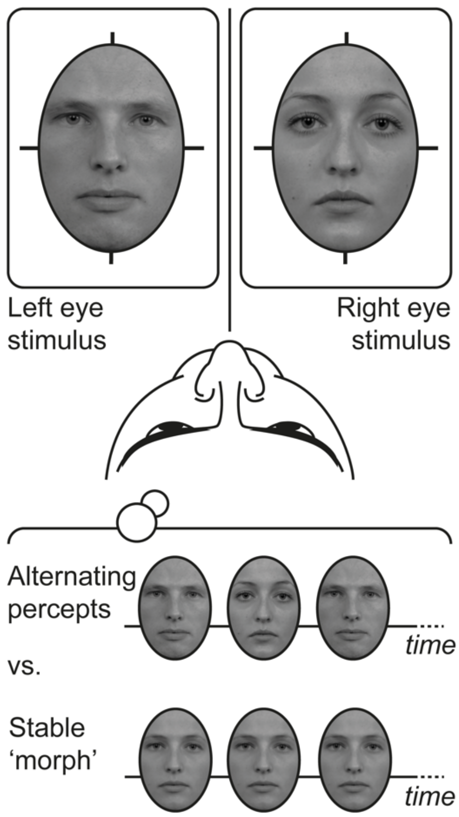

Figure I

Figure I (Box 1). Binocular rivalry stimuli. The masculine face is presented to the left eye and the feminine face to the right eye. If the subject is attending to local features or parts such as the eyes, standard binocular rivalry ensues. This is indicated by the label "alternating percepts" and illustrated as first a masculine face, then a feminine face, then a masculine face. If the subject is attending to holistic features such as gender or the identity of the person, the subject sees a persisting morphed androgynous face ("stable morph"), as pictured. Thanks to Chris Klink for this figure. See [25].

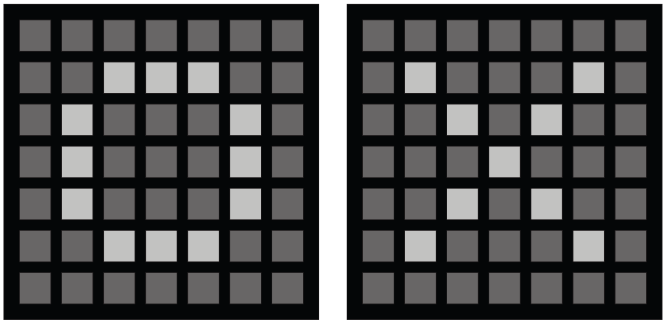

Figure II

Figure II (Box 1). Stimulus Showing the Local Nature of Rivalry. These are sample stimuli used in a binocular rivalry experiment. Each image is projected to a different eye. Thanks to Thomas Carlson for this figure. See [26]