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Visual Perception: Human Brain Cells Cause a Change of View

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Some images spontaneously change in appearance. A new study has found that these changes are reflected in high-level visual cortical areas before they become apparent in early sensory cortex. This suggests that visual information not only flows towards interpretative areas of our brain, but also in the reverse direction.

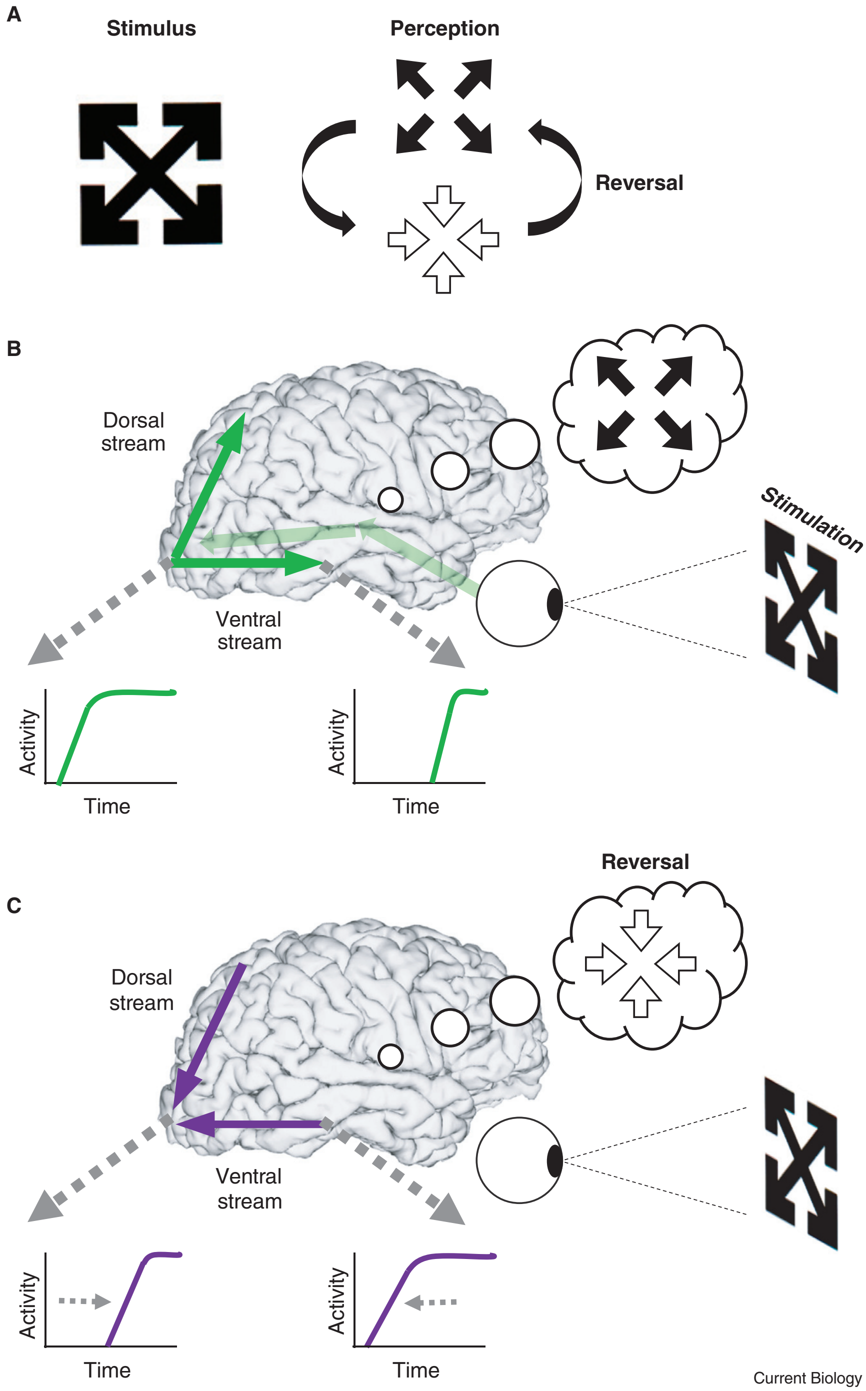
A common cliché of skeptics is to “only trust one’s own eyes”. Yet numerous visual images call into question this solipsistic criterion for discerning facts about the world. So-called bistable visual stimuli, such as the one shown in Figure 1A, cause our brains to frequently reconsider their own interpretation of sensory information. As long as we look at these visual patterns, our brains repeatedly go back on themselves. As a result, our perception spontaneously alternates between two views of one and the same stimulus [1].

Neuroscientists take great interest in bistable stimuli because they allow for interesting experiments where perception changes while the physical world — the retinal stimulation that provides input to the brain — is held constant. Under these conditions, brain activity can be measured with perception as the sole changing variable. In this issue of *Current Biology*, de Jong *et al.* [2] address the long-standing question where in the brain these reversals of perception originate. To do so, they used direct measurements of human brain cell activity during perceptual reversals and compared these responses to physical stimulus changes. To best appreciate these findings, we must first review how visual brain responses are triggered by changes in the physical world.

Whenever we are confronted with a visual image, our brain responds with a wave of activity [3]. This wave originates from the retinae in the back of our eyes, travels subcortically to the primary visual cortex (V1) that is located at the back (the posterior end) of our head. The wave then diverges and proceeds within two ‘streams’ of activation towards the frontal cortex [4] (Figure 1B). One way that this cascade of visual responses can be demonstrated is by measuring the average time (latency) with which neurons respond to the onset of the visual image. When comparing latencies from posterior to more anterior (frontal) regions of cortex, mean latency rises systematically [5]. This and other observations have given rise to the idea that the visual system is organized in a hierarchical manner [6], with posterior visual cortex responding ‘earlier’ than ‘higher’ anterior visual cortical areas. In line with this assumption, simplistic and highly localized visual features such as contours, edges and boundaries drive early visual cortex [7], while high-level visual cortex responds more holistically to large and complex visual patterns, such as faces and houses [8].

In addition to this ascending ‘bottom-up’ wave of cortical responses following visual stimulation, there is also an inverse ‘top-down’ stream of activation. Specifically, neurons in early visual cortex do not just receive ‘feedforward’ inputs that arise from the eyes. As part of their dense web of connections, early cortical neurons also receive ‘feedback’ from the visual cortical areas that they feed information to. Indeed, there are many neurons in early visual cortex that do not respond until after a large number of neurons have responded further downstream [5]. One reason for this design might be that neurons in early visual cortex perform better at discriminating local details of a visual image once higher visual areas have interpreted the gist of what is seen and signaled this information back to the initial stages of visual processing. This idea has been captured by the so-called ‘reverse hierarchy’ hypothesis [9]. This reverse hierarchical processing seems especially relevant to resolving bistable visual stimuli, as they show a change in the holistic interpretation of these sensory stimuli, a hypothesis De Jong *et al.* [2] sought to investigate.

Previous human neuroimaging work pointed to either higher cortical areas (especially in the frontal lobe [10]) or early visual cortex (V1) [11] as initiating perceptual reversals. This apparent discrepancy has triggered lively debate [12,13]. Higher cortical areas are not exclusively concerned with the



Current Biology

Figure 1. Brain responses to physical and illusory visual events.

(A) Bistable images are a special class of stimuli that evoke more than one, equally valid perceptual interpretation. In the example shown here (below the label ‘stimulus’), observers typically perceive either a set of black arrows protruding outward from a common center (see idealized schematic to the right under the label ‘perception’), or a set of white arrows that are superimposed on a black square that point inward (see lower schematic under the label ‘perception’). Prolonged inspection of a bistable stimulus causes observers to perceive a randomly fluctuating series of ‘reversals’ between the two rival perceptual interpretations. (B) Visual stimulation evokes a wave of ‘feedforward’ activity that first travels from the eyes towards the visual cortex to the posterior pole of cortex (light green arrows), and then along two ‘streams’ of cortical areas towards the anterior front of the brain (dark green arrows). One way to demonstrate this ‘ascending’ hierarchy of visual cortical activation is to compare the responses of neurons in posterior to anterior visual cortex (see schematics at bottom). Because visual signals first arrive in the posterior visual cortex, neurons in that part of the brain tend to respond before neurons in more anterior regions of visual cortex. (C) Endogenous (illusory) perceptual reversals evoke a ‘reverse hierarchy’ pattern of cortical responses. De Jong *et al.* [2] found that, when cortical responses are aligned to the moment that observers report a bistable image to change its appearance, neurons in anterior regions of cortex tend to respond before neurons in more posterior regions of the brain, suggesting that visual signals flow in the opposite direction to sensory signals whenever perceptual reversals occur (purple arrows). Brain images from ‘Cross-sectional’ dataset provided by OASIS: https://www.oasis-brains.org/

processing of visual information, but are also involved in determining and guiding action. Some authors have worried that the reversal-associated activity in frontal lobe might be more related to an observer's report of the perceptual change than the change in perception itself. Indeed, several studies aimed at foregoing an immediate report of perceptual reversals found that the activation of the frontal lobe disappeared [14]. Does it follow that perceptual reversals are created in a bottom-up rather than top-down fashion?

One problem associated with most human neuroimaging techniques is that they provide great spatial coverage (up to the whole brain) at the expense of temporal resolution (usually in the range of seconds). In other words, using standard neuroimaging, it is challenging to resolve whether one part of the brain responds ahead of another. This limitation can be circumvented by directly measuring the activity of single or larger populations of brain cells. However, direct neuronal measurements are typically limited to animal models, which pose significant challenges for the acquisition of accurate perceptual report during bistable perception [15].

De Jong *et al.* [2] overcame all of these restrictions by studying the activity of brain cells in humans that reported their perceptual alternations during a form of bistable visual stimulation known as binocular rivalry [1,16,17]. Studies of this kind are practical in small groups of neurological patients that undergo surgical interventions to treat severe forms of epilepsy. Prior work on such epileptic patients demonstrated that the activity of single neurons in human temporal cortex covaries with perception during binocular rivalry [18]. De Jong *et al.* [2] elaborated these findings by measuring rivalry-associated responses in both these higher visual cortical areas in the anterior temporal lobe as well as early visual cortex in the posterior occipital lobe. This experimental setup allowed the authors to compare the relative onset of neural responses in both regions of the brain to both physical visual stimulation as well as endogenously generated (illusory) perceptual reversals.

Strikingly, there was a profound difference in the neural latency to physical versus illusory visual events. Physical stimulation evoked the expected pattern of a steep rise in responses in occipital followed by temporal cortical neurons. In contrast, the illusory reversals showed a more sluggish change in activity that took on the inverse temporal order, with temporal lobe responses preceding those of the occipital cortex. In other words, the internally generated perceptual transitions indeed resembled a reverse hierarchy: Visual cortical areas that are more involved in interpreting visual stimuli lead early visual cortex in signaling the perceptual change (Figure 1C).

Fresh insight begets new questions. Previous behavioral work suggested that binocular rivalry between rather simple visual stimuli, such as tilted sets of lines, might be predominantly processed by early visual cortical areas. Binocular rivalry between faces and houses — as used by De Jong *et al.* [2] — on the other hand might invoke differential processing by higher-level visual areas [19]. Therefore, it would be interesting to learn whether the current finding is specific to complex images or generalizes to other visual stimuli.

It is exciting to think about the myriad of possibilities that arise from the relatively recent technical advancement of recording brain cells across many cortical areas in humans. By revealing a new twist on the brain mechanisms that give rise to our perception, De Jong *et al.*'s [2] work demonstrates that employing this methodological advance helps build an important bridge between electrophysiology in animals and non-invasive neuro-imaging in humans.

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