Single neuron consciousness in the binocular brain

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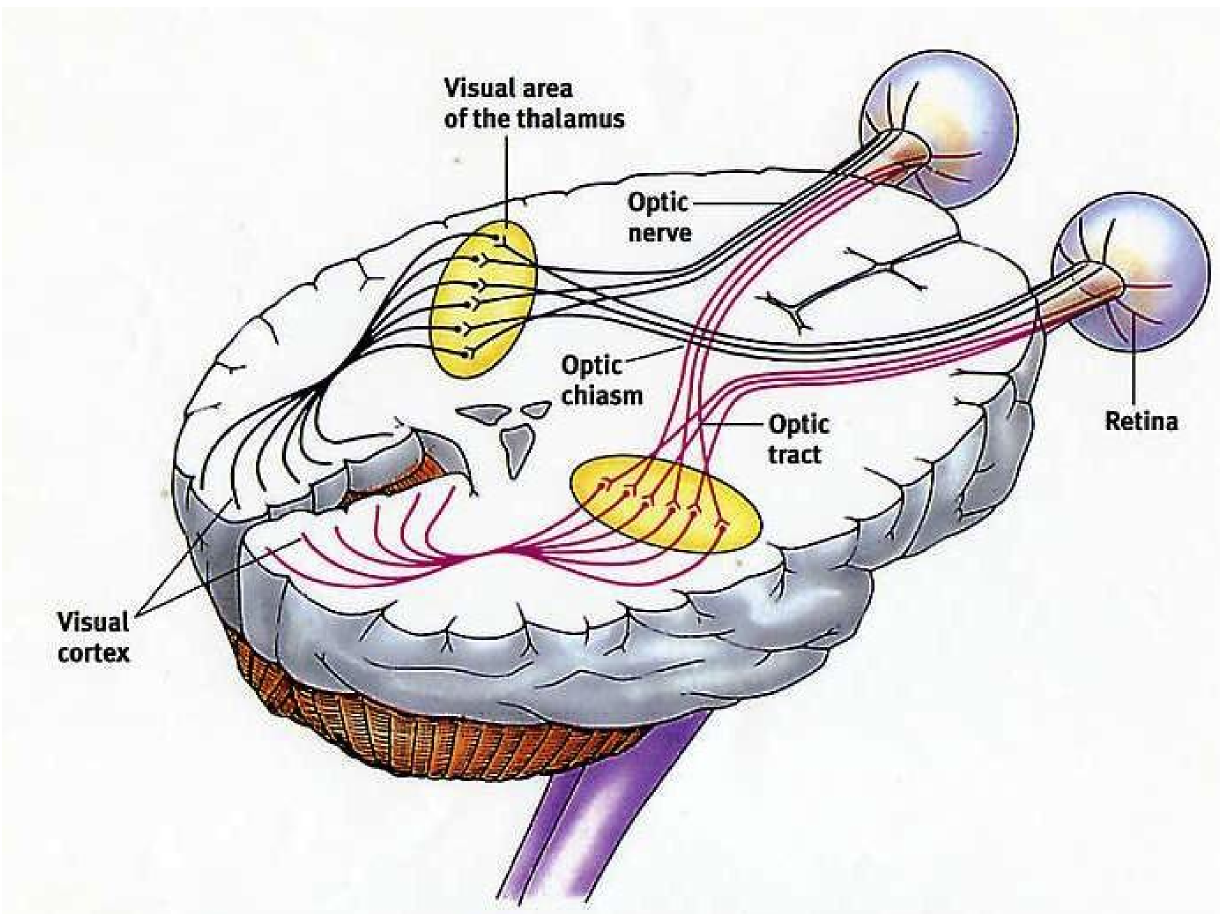

Visual system pathways. Credit: Chinadrifter.blogspot.com

In contrast to unpaired organs like the heart, liver or appendix, the brain is recognizable as a roughly symmetrical organ. Consciousness is a seemingly unpaired phenomenon created by this paired organ. One way to explore consciousness is to force it to choose between two paired stimuli in a binocular rivalry experiment.

In a paper just published in *Nature Communications*, Christof Koch and others simultaneously presented different images to each eye and recorded activity from neurons in different cortical regions. What typically happens in these experiments is that perception of the two stimuli will alternate; first, one image will dominate, and then the other. The researchers found that individual neurons in the medial frontal lobes signaled an internal shift in perception about 2000 ms before human subjects even reported consciously experiencing it. Similarly, they found medial temporal lobe neurons were subsequently activated approximately 1000 ms before the shift.

Experiments done in the mid-90s by Nikos Logothetis and others showed that as the visual hierarchy in the brain is ascended, more cells will correlate their activity to the internal percept. These particular experiments were done in monkeys before the big animal rights crackdown and could not be readily replicated today. These researchers found that in the primary visual cortex, about 20 percent of the recorded neurons had activity that was correlated to the perception. Slightly higher up the visual chain in the inferior temporal cortex this fraction increased to 90 percent.

The more recent findings by Koch et. al. showing that clearly correlated activity extends up to our cherished frontal lobes and other elite cortical areas raises a few interesting questions. For example, what else is the subject thinking during these experiments? Would this neural activity modulated by other simultaneously delivered sensory inputs as it is for primary visual areas? Experiments have shown that visual input can control, at least to some extent, what we hear or smell. Would the opposite effect occur, ie., would smells affect what we visually perceive in something like a binocular rivalry task?

The answer appears to be that odors do influence rivalrous perception. For example, when visually presented with a rose to one eye and a pen to the other, subjects visually tended to perceive the rose when the scent of rose oil (phenylethyl alcohol) was introduced. Unfortunately, there was no recording of individual neurons during these experiments. That odors can also compete with each other for conscious attention suggests a more generalized rivalry is at play in many sensory phenomena. The factors that influence shifts in rivalry can be subtle. In vision, miniscule eye movements, local adaptation, shifts in accommodation, or purely internal whims of attention all influence the rate depth of binocular rivalry. To make any real progress in this arena, it would seem that our experiments need to get a lot better.

For that matter, we might expect that the anatomical specifics of each subject need to be considered in much greater detail. In the human visual system, each eye projects to both hemispheres, while for smell, the major cortical projection from each nostril goes directly to the ipsilateral side. However, short of having a whole matter connectome, these crude anatomical statements don't offer us much. Smell itself is subject to its own form or perceptual rivalry. While our closely spaced nostrils hardly appear useful for stimulus localization, there is a lot of evidence that suggests the emotional percept of an odor depends on which part of the brain processes it. In other words, the value judgment of any given odor, ostensibly either good or bad, may actually be more rivalrous then we might at first imagine.

Many birds and fish are interesting cases for perceptual rivalry in vision. They tend to have wide fields of view with only limited binocularity. These animals are well suited to look at the question of brain asymmetry because each optic nerve almost completely crosses to the opposite hemisphere. They also have only limited commissures extending between their main hemispheres. Many birds show surprisingly strong behavioral preferences for one eye or the other. For example, they will orient their bodies so that they can selectively bring to bear a favored hunting eye. When studying larger predators, these same animals may in turn orient themselves to use the opposite eye. In zebrafish, neurons in the right side of the habenular region have been found to specifically process odors, while those on the left process visual inputs. The outputs of these neurons also wire up respectively to odor and visual regions.

Rivalry experiments tell us that our brains abhor inconsistency. Rather than continue to accept rivalrous stimuli, they make one or the other disappear altogether. In learning to identify objects by touch, it is important that both hands and both hemispheres maintain some agreement—a ball should feel like a ball regardless of which arm holds it. While this makes for a great learning tool, such duplication of effort would seem inefficient for many higher functions of consciousness. Ultimately, it does not seem that we will be able to advance much in this arena, even with complete connectomes in hand, unless the experimenters become the actual subjects of the experiments themselves.

Today, this would mean that the people asking the questions would not only need to have their own sets of electrodes in place within their heads, but also have them in contact with the 'right' neurons. In other words, have the ability to record from neurons that do what what is desired rather than those which just happen to be accessible because somebody is preparing for epilepsy surgery and wants to preserve some eloquent function. Fortunately for us, the would be experimenter-patient has a special power in their corner. Namely, the hither-to-unimagined plasticity of the individual neuron.

Studies have shown that mice can rapidly learn to reinforce patterns of synaptic activity in single neurons. In fact, they can do this in many neurons. In other words, once the researchers choose a particular cell, the mouse could route activity to it in such a way that it could receive a reward. In these experiments, the reward was a highly coveted electrical stimulation pulse to the lateral hypothalamus. What this means is that rather than having to find special neurons that anatomically link up to desired visual, olfactory, and speech areas, we might simply auto-train any reasonably well-connected neuron to become a virtual command neuron.

How to do all this training? Experimenters can't control what other people are thinking. However, they can certainly control what they themselves are thinking. To my knowledge, the only experimenter to become the experimentee in a deep-brain physiology experiment is Phil Kennedy. Although he got a great Society for Neuroscience abstract out of his studies, he nearly paid for it with his life. In talking to him, it quickly becomes clear that there is ample room for improvement both in the Belizean surgical facilities he used, and also the electrodes he designed and fabricated himself.

One immediate area for improvement is getting more out of each neuron you can record from. In their paper, Koch et. al. highlight the challenge of "bridging the gap between the binary activity of single neurons and the complexity and vividness of conscious experience." This is actually a gross mischaracterization. Neurons are not binary. There is not even a single transmitter-filled vesicle in a single synapse that is binary. To illustrate this fact, we need look no further than experiments done by Jose Carmena's group at Berkeley.

These researchers used two-photon calcium imaging to record all neural activity within a 150 x 150 μm field of view for layer III in the mouse motor cortex. These neurons expressed the genetically encoded calcium indicator gCaMP6f, and were trained to modulate their neural activity up or down in response to the changing pitch of an auditory cue. Incredibly, the mice could train their own neurons in just a few days. By using the full subcellular optical activity of any given patch of brain in this way, researchers can get a much better predictor of any intent or perception.

More information: Hagar Gelbard-Sagiv et al. Human single neuron activity precedes emergence of conscious perception, *Nature Communications* (2018). DOI: 10.1038/s41467-018-03749-0