ON CELLS (ON CELLS)?

Authored by
mohammad looti

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Primary Disciplinary Field(s): Neuroscience, Sensory Physiology, Vision Science

1. Core Definition

ON cells represent a fundamental class of neurons found within the vertebrate retina, which is the light-sensitive tissue at the back of the eye. These cells are defined by their physiological response: they become highly excitable, or depolarize, specifically when light intensity increases, marking the transition from darkness to illumination. This response mechanism is crucial for the initiation of the visual signal that is transmitted to the brain. Structurally, the term most often refers to **ON bipolar cells** and **ON ganglion cells**, which form a distinct parallel pathway dedicated to processing increments in luminance.

The defining characteristic of an ON cell is its sensitivity to the onset of light. As the source content states, "On cells are excited the most when light occurs immediately following darkness." This immediate, often transient, burst of activity allows the visual system to quickly register changes in the environment, which is critical for motion detection and tracking moving objects. The underlying molecular mechanism for this response involves a unique signaling cascade where the input signal is inverted before transmission, a process essential for separating the visual stream into brightness-detecting and darkness-detecting components.

In essence, the entire visual system relies on comparing illumination states. The ON pathway signals "brighter now," while the complementary OFF pathway signals "darker now." The separation of these two pathways begins at the first synapse in the retina--the interaction between photoreceptor cells (rods and cones) and bipolar cells. This bifurcation ensures that the central nervous system receives distinct, unambiguous information about both increases and decreases in light intensity across the visual field, optimizing contrast detection and spatial acuity.

2. Location within the Visual Pathway

The ON cell pathway originates at the photoreceptors. In darkness, photoreceptor cells continuously release the neurotransmitter **glutamate**. When light strikes the retina, these photoreceptors hyperpolarize (become more negative) and thus reduce their release of glutamate. This decrease in glutamate is the critical stimulus that activates the ON cells, demonstrating a unique form of signal inversion at the synaptic level.

The primary location for the ON response mechanism is the synapse between the photoreceptors and the **ON bipolar cells**. These specialized bipolar cells express a unique type of glutamate receptor, specifically the metabotropic glutamate receptor subtype 6 (mGluR6). Unlike typical ionotropic receptors that depolarize a cell upon neurotransmitter binding, mGluR6 receptors are inhibitory. Thus, when glutamate is high (in darkness), the ON bipolar cell is inhibited (hyperpolarized). When light causes the glutamate release to drop, the inhibition is removed, leading to the depolarization (excitation) of the ON bipolar cell. This metabolic inversion is the defining feature of the ON pathway.

Following the ON bipolar cells, the signal is passed to **ON ganglion cells**. These ganglion cells are the output neurons of the retina; their axons bundle together to form the optic nerve. The ON ganglion cells inherit the light-onset sensitivity from the bipolar cells, firing action potentials only when light hits their receptive field center. These action potentials travel directly to central brain areas, such as the Lateral Geniculate Nucleus (LGN), ensuring that brightness information is faithfully transmitted for cortical processing.

3. Mechanistic Physiology and Receptive Fields

The functionality of ON cells is best understood through the concept of the **receptive field**, which is the specific area of the visual world that, when stimulated, affects the firing rate of the neuron. Pioneering work by Stephen Kuffler in the 1950s established that retinal ganglion cells, including ON cells, possess receptive fields structured with a concentric organization: a center and an antagonistic surround.

For an ON cell, the receptive field is typically described as "ON-center, OFF-surround." This means that shining a small spot of light onto the center of the field causes a vigorous excitation (depolarization and increased firing). Conversely, illuminating the surrounding area inhibits the cell (hyperpolarization and reduced firing). If both the center and the surround are illuminated diffusely--as happens in uniform lighting conditions--the effects tend to cancel each other out, resulting in a weak response.

This antagonistic center-surround organization is not an accident; it is the fundamental neural mechanism underlying the detection of **contrast and edges**. The ON cell is maximally activated when there is a sharp difference in light intensity between its center and surround--for instance, when a bright object falls precisely on its center, adjacent to a dark background. This mechanism filters out uniform illumination and highlights the spatial discontinuities that define the contours of objects in the environment, making the visual system an extremely efficient edge detector.

The specific inhibitory process in the surround is mediated by horizontal cells and amacrine cells, which provide lateral connectivity across the retina. When the surround is illuminated, these lateral inhibitory circuits are activated, suppressing the signal generated by the center pathways. This lateral inhibition enhances the contrast sensitivity, sharpening the boundaries that the ON cells report to the brain.

4. Contrast with OFF Cells: Parallel Processing

The existence of ON cells necessitates the existence of their functional complements, the **OFF cells**, creating parallel pathways that handle increments and decrements of light simultaneously. This parallel processing architecture is a hallmark of the visual system and ensures rapid, comprehensive coverage of visual input.

While ON bipolar cells are inhibited by glutamate via mGluR6 receptors, OFF bipolar cells utilize ionotropic glutamate receptors (such as AMPA and Kainate receptors). These ionotropic receptors are excitatory; thus, the continuous release of glutamate in the dark depolarizes (excites) the OFF bipolar cell. When light strikes and glutamate release drops, the OFF cell becomes hyperpolarized and stops firing. Therefore, OFF cells fire maximally when light is turned off (darkness onset), providing the brain with parallel information regarding areas that are dimming.

The segregation of these pathways (ON vs. OFF) occurs physically in the retina's inner plexiform layer (IPL). ON bipolar cells synapse in the inner half of the IPL, while OFF bipolar cells synapse in the outer half. Similarly, ON ganglion cells extend dendrites primarily into the inner half, and OFF ganglion cells extend into the outer half. This layered segregation is critical for maintaining the functional independence of the brightness and darkness signals before they exit the retina via the optic nerve. If these two channels were mixed, the brain would receive ambiguous signals, significantly impairing the ability to perceive sharp edges and rapid changes in luminance.

5. Role in Transient and Sustained Responses

The response dynamics of ON cells are frequently characterized as being either **transient** or **sustained**, reflecting different functional roles in visual processing. Transient ON cells are characterized by a sudden, intense burst of action potentials immediately following light onset, which then quickly declines, even if the light remains on. This rapid, short-lived firing pattern is highly efficient at encoding temporal changes.

Transient ON cells are paramount for motion detection. Because they respond maximally to the change itself ("excited the most when light occurs immediately following darkness") rather than the steady state, they provide timely information about movement across the visual field. These cells typically project to the magnocellular pathway of the LGN, which specializes in high temporal resolution and low contrast sensitivity, critical attributes for tracking fast-moving targets.

In contrast, some ON cells exhibit a more **sustained** response, continuing to fire at a moderate rate for the duration of the light stimulus. These cells are better suited for encoding static spatial information, such as the fine detail of objects and texture. Sustained ON cells generally feed into the parvocellular pathway of the LGN, which specializes in high spatial resolution and color processing. The existence of both transient and sustained ON cell populations illustrates how the visual system partitions the input signal not only by polarity (light vs. dark) but also by temporal characteristics (change vs. presence).

6. Significance and Impact

The discovery and detailed understanding of ON cells revolutionized visual neuroscience, providing the empirical foundation for how the brain processes contrast and visual features. Before the identification of these separate channels, it was unclear how a single photoreceptor signal (hyperpolarization in light) could encode both increases and decreases in illumination. The ON pathway demonstrated that signal inversion is a necessary, early step in generating useful feature information.

The functional significance extends far beyond basic light detection. The antagonistic receptive fields implemented by ON cells are the biological basis for concepts like lateral inhibition, which is crucial for phenomena such as the Mach bands illusion, where perceived contrast is exaggerated at the boundaries of different shades. This demonstrates that the visual representation of the world is not a direct, faithful reproduction of light intensity but rather a highly processed, contrast-enhanced interpretation engineered to highlight edges and motion.

Furthermore, understanding ON cell failure is vital for clinical ophthalmology. Certain diseases, such as congenital stationary night blindness (CSNB), are often linked to genetic defects in the components of the ON bipolar cell cascade, specifically mutations affecting the mGluR6 receptor or downstream signaling proteins. This results in an inability to see well in dim light conditions because the ON pathway, which is heavily utilized by rod photoreceptors, fails to depolarize upon light exposure, leaving the patient reliant solely on the less sensitive OFF pathway.

7. Further Reading

Retinal Ganglion Cell (Wikipedia)
Bipolar Cell (Wikipedia)
Lateral Inhibition (Wikipedia)
Neuroscience of the Retina (National Center for Biotechnology Information)