

# Seeing what is absent: The science of vision and reality

*The night was dark as I participated in a military field exercise deep within a Norwegian forest. After several days of hard labor and almost no sleep or food, I suddenly spotted a bright gasoline station among the trees. Soon, it disappeared, overtaken by the darkness once again.*

What I experienced was a dreamlike hallucination. My tired brain could not distinguish between fantasy and perceptions of reality. “The problem of perception” has intrigued philosophers for 2,500 years: If hallucinations and illusions are possible, how can we be sure that we recognize external objects correctly (Figure 1)? Indeed, seeing something that is not there is, in some ways, universal. Let me explain how and why.

## Dream or die

Hallucinations arise in the waking state in the absence of outer stimuli when prior expectations and beliefs override our senses. In one study, 4% of the participants, many without mental health issues, reported hallucinations in the past 12 months. More than 70% of patients with schizophrenia have hallucinations.<sup>1</sup> Other causes include psychoactive drugs, high caffeine consumption, fever, Parkinson’s disease, Alzheimer’s disease, brain tumors, and epilepsy.

They can be mild. Sensing movement in the peripheral visual field is a common phenomenon related to tiredness. However, sensory disturbances can also occur while falling asleep (hypnagogic hallucinations) or waking up (hypnopompic hallucinations). You may

feel someone touching you, hear sounds or words, or even see people lying next to you in your bed. These hallucinations may be mistaken for nightmares. Moreover, sleep paralysis, misinterpretation of stimuli, and perhaps lowered temporal lobe sensitivity to magnetic frequencies may explain alleged sightings of ghosts and extraterrestrials (Figure 2).

Hallucinations show similarities to dreams. Our most vivid dreams take place during rapid eye movements (REM) sleep. REM sleep and dreams are crucial for maintaining our emotional sanity, by resetting norepinephrine levels and activating the amygdala, as well as our creative skills, by forming new associations. Sleep fewer than 6–8 hours each night, and the risk of diseases increases. Go without sleep for a fortnight,

exist due to an eye disease. Charles Bonnet syndrome is named after him. It occurs mainly in older people who suffer from sight impairment such as macular degeneration, glaucoma, or cataract. The hallucinations can be simple, consisting of shapes, grids, and lines, or they can be very complex with hallucinations of people, animals, and cartoons. They can last up to hours, but more often, only minutes. Neural hyperactivity in the visual cortex may explain these symptoms.<sup>3</sup> Symptom manifestations have increased during the Covid-19 pandemic, possibly related to loneliness or environmental factors. Unlike those with mental illnesses, the patients are well aware that the visions are not real, but they often refrain from informing doctors about them.

Visions have played a significant role in human history. In some cultures, shamans used hallucinogenic plants to reveal the will of the gods during a trance. In 312 AD, leading up to a battle, emperor Constantine saw the victory sign of a cross (or the Greek letters *chi* and *rho* superimposed) in the sky. The outcome was the Christianizing of the Roman Empire and a world forever changed.

## You are partially blind

You are blind—at least, to some extent. The physiological blind spot in our visual

field is due to the lack of photoreceptors in the optic nerve head (Figure 3). Our inability to recognize this significant visual field defect is an example of a negative scotoma, the opposite of a positive scotoma, where people perceive the visual disturbance. Therefore, the brain has to fill in the missing part (Figure 4). There are two competing hypotheses for how the brain accomplishes this. According to the isomorphic theory, a two-dimensional array of neurons represents the absent surface. Neurons in the border zone stimulate them to fire. On the other hand, the symbolic theory posits that perceptions of surrounding textures are copied into the enclosed surface.

Patients with moderate glaucoma do not experience “black tunnels” or gray



Atle Einar Østern, MD,  
Oslo University Hospital HF (Ullevål)

Figure 1. Representative realism is a central philosophical idea that we see only an indirect miniature replica of the external world. Diorama: Atle Østern

and you may die. (This is why the *Guinness Book of Records* has stopped certifying attempts to stay awake for more than the current record, which, by the way, is 11 days). However, so far, no one can provide a complete explanation of why we must spend approximately 30% of our life in a semiconscious state.<sup>2</sup> There is a significant overlap between hallucinations and dreams regarding the involvement of brain mechanisms. However, during sleep, only a subset of the neural network is activated.

Eye diseases may also generate hallucinations. The first to report such findings was the Swiss scientist Charles Bonnet (1720–1793). He noticed that his grandfather saw things that did not



Figure 2. Because bilateral eyes have evolved more than 40 times in different animals, it is likely that extraterrestrials would also have two eyes. (Or might they be time travelers from our distant future, as some have suggested?). Illustration: Atle Østern



areas as often depicted.<sup>4</sup> The lack of these symptoms is not well understood. New research suggests that for suprathreshold stimuli, the mechanisms of contrast constancy in the brain compensate for significant sensitivity loss during the earlier stages of the disease.<sup>5</sup>

Amazingly, our familiar impression of a colorful, detailed peripheral vision is, for the most part, a delusive sensation created by the brain's perceptual filling-in. In a study, most people failed to recognize the total removal of colors from most of the visual field except for the central part.<sup>6</sup>

### Fireworks in the visual field

Occasionally, I suddenly sense a slight quivering in the temporal part of my visual field. Then, it enlarges, with bright white, central, visual disturbances that last for 15–20 minutes. What I see are classical



Figure 3: The diameter of the blind spot is substantial (6°) and equals 12 full moons side by side, since the moon makes up only 0.5° of the night sky. Photo: Atle Østern

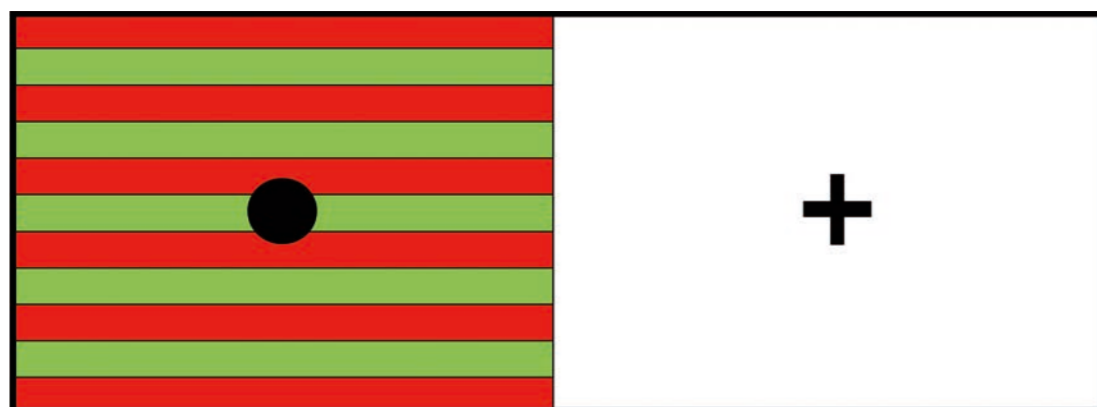


Figure 4: Perceptual filling-in. Focus on the cross, close your right eye and slowly move the page towards you. At some point, the black dot will disappear when it coincides with the blind spot. The stripes then replace it. Illustration: Atle Østern

scintillating positive scotomas with zigzag lines (fortification spectra, teichopsia). However, a headache, like in a common migraine, never follows it. Migraine aura without headache, previously called “migraine equivalents” or “acephalgic migraine,” is rare, according to reports. The incidence among migraine patients is 4%.<sup>7</sup> What causes aura? The pathogenesis is still not fully understood.<sup>8</sup> Previously, a vascular mechanism had been hypothesized. However, new research suggests that, instead, a cortical neuronal depression spreads from the occipital lobe (Figure 5).

Migraine aura (without headache) must be distinguished from ocular or retinal migraine due to temporary constrictions

of retinal blood vessels. The symptom is then a transient monocular vision loss.

Flashes of light, as seen in migraine, are called photopsia. Phosphenes are photopsia not related to an external light source. If you close your eyes, you may observe flick phosphenes in the form of slowly dancing dots, stars, and worms. Even in the total absence of light, the background is perceived not as entirely black but rather a dark grayness, known as *Eigengrau* or visual noise. What happens is that the endlessly active cells in the visual system spark electrical charges, either as a result of thermal processes in photoreceptors—or, as recently suggested, inherent biophoton emissions. Mechanical forces can also induce

phosphenes, such as retinal traction, eye rubbing, coughing, head trauma, and optic nerve compression.<sup>9</sup>

Moreover, people deprived of visual stimuli for a long time may experience phosphenes, nicknamed “prisoner’s cinema.” A strong electromagnetic field can also produce them. For example, astronauts have reported phosphenes during trips to space after exposure to high radiation levels and subsequent free radical formation in the retina.

Other conditions associated with photopsia are ischemia (such as vertebral basilar insufficiency and orthostatic hypotension), degenerations/inflammations (such as neovascular age-related macular degeneration, multiple

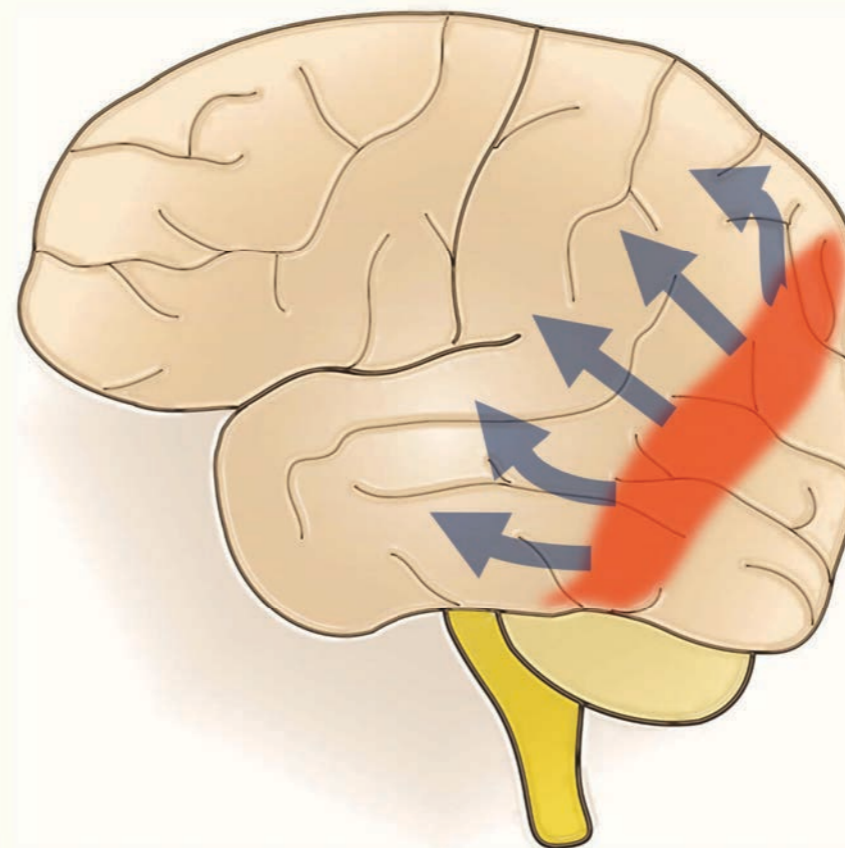


Figure 5: Cortical spreading depression. The visual aura of migraines probably involves a hyperexcitation of the occipital cortex and a slow wave forward (1.5–9.5 mm/min.) of depolarized neurons and glial cells. Illustration Atle Østern

evanescent white dot syndrome and optic neuritis), retinitis pigmentosa, paraneoplastic retinopathy, and intracranial hypertension.

### Visual deceptions

Frequently, I notice that colored letters seem to pop out from dark book covers; chromatic aberration creates this illusion. Optical illusions are images that deceive the eye and brain into interpreting them as something they are not.<sup>10</sup> There are three categories: physical, physiological, and cognitive illusions. An example of a physical phenomenon is a Fata Morgana, the illusion of a ship hovering above the horizon, caused by the bending of rays of light that intersect with distinct air layers of varying temperatures. Afterimages are physiological illusions of a prolonged visual impression following the termination of the initial exposure. Positive afterimages that retain colors are very brief. Negative afterimages persist longer with reversed complementary colors after

motion in some images.

Magicians exploit these illusions as well as our attention awareness when they perform their tricks.<sup>11</sup> Patients with osteoarthritis have even reported experiencing reduced pain after repeated exposure to a visual illusion of a changed knee size.<sup>12</sup> The out-of-body illusion is the extraordinary experience of feeling or observing the body from the outside, often induced by external stimuli or epilepsy. To generate the usual coherent, spatial sense of self located within one’s own body, visual and proprioceptive signals must be integrated by parietal and temporal neurons, as well as “place cells” in the hippocampus.<sup>13</sup>

Children can, on rare occasions, suffer from the so-called “Alice in Wonderland” (Todd’s) syndrome. During such episodes, they may perceive themselves as enlarged or diminished in size.<sup>14</sup>

### Reading the unwritten

Our brain has a remarkable capacity to encode vague visual perceptions. Context is essential. That becomes evident when you read (or fail to identify) misspellings: I assume you... cn still ndrstd ths txt. Written Arabic relies on this skill because there are no letters for vowels, although the language contains several.

Researchers have recently identified a brain region called the mid-fusiform cortex,

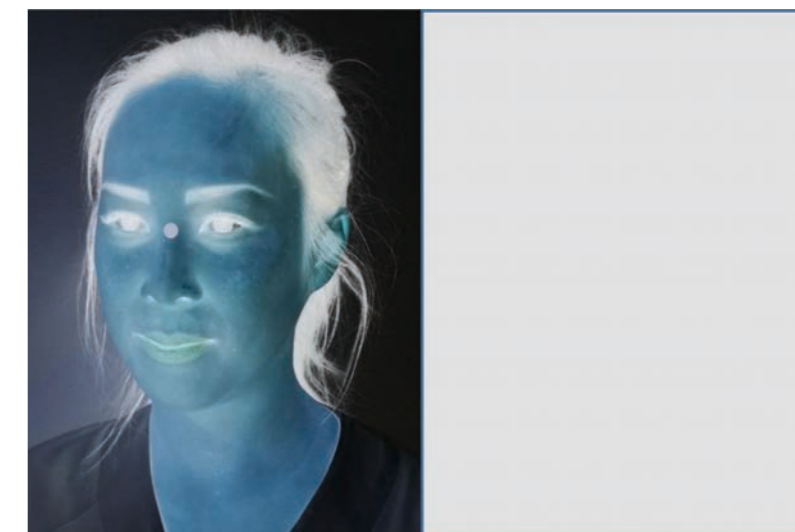


Figure 6: Negative photo illusion. Gaze at the gray dot between the eyes for 30–60 seconds, then abruptly shift attention to the gray area to the right of the face and blink several times. A reversed color photo appears. The explanation is that reduced microsaccades lead to the adaption of photoreceptors with sensitivity loss. In contrast, the brain interprets strong signals from the surrounding cones as opposite colors. Illustration: Atle Østern

which acts as a primary visual dictionary during reading. A disruption here may lead to dyslexia, which causes problems with arranging letters in the correct order.<sup>15</sup> The prevalence is 5–17% (among them the former prime minister Solberg of Norway and the king of Sweden).

Some people perceive black letters as having colors, which is the most frequent form of synesthesia. Synesthesia, which affects approximately 4% of the population, is a neurological condition in which one sensory input induces a

response in another pathway.<sup>16</sup>

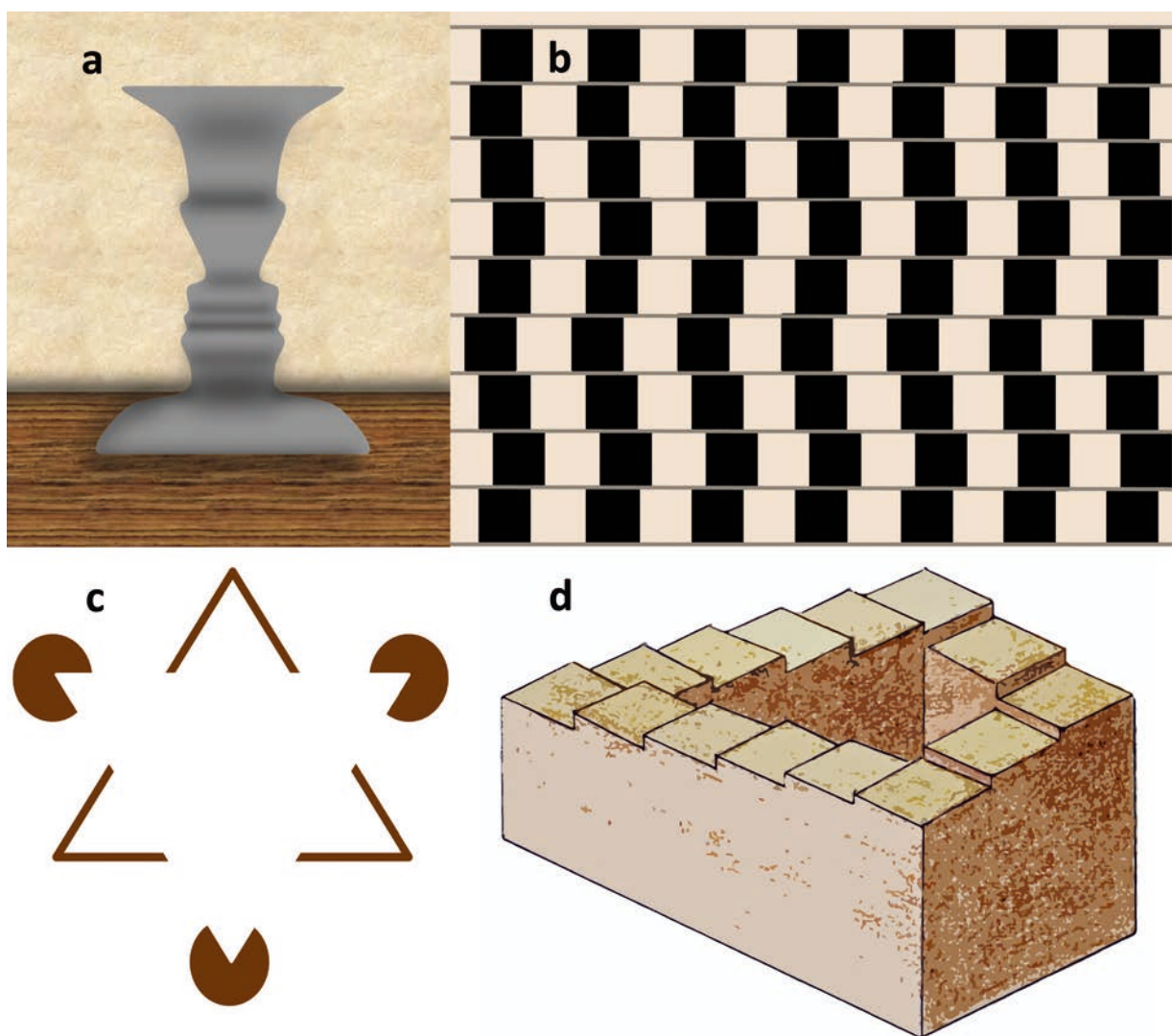
**So, can we believe our eyes?**

As this article has shown, the simple answer is “not always.” The visual process is super fast and efficient, which conceals how complex it is. In some situations, it malfunctions. It fools us.

Our brain must reconstruct reality to make sense of our external surroundings. Five hundred years ago, everybody “knew” that the earth was the center of the universe because it intuitively looked

that way. Science disproved that idea. But perhaps reality is much stranger. What if our notion of space is only a misperception and that we actually live on the surface of a two-dimensional hologram, as some physicists seriously suggest? Or that we exist within a Matrix-like simulation? Elon Musk and others believe so.

Who knows, really? Anyway, the only sure thing is that what you perceive is literally “for your eyes only,” to quote the title of a Bond movie.



**Figure 7: Cognitive illusions.**  
 (a) ambiguous illusion (two faces or a vase?);  
 (b) distorting illusion (parallel lines appear tilted);  
 (c) fictional illusion (perceiving a non-existent white triangle);  
 (d) paradox illusion (never-ending stairs).  
 Illustration: Atle Østern

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