Entoptic Phenomena

Vision is supposed to tell us about the world beyond ourselves, but sometimes what we see is caused by the visual apparatus itself. Because they come from “inside” they are called “Entoptic” phenomena. Perception often filters these images out, but when they have sudden onset or become annoying, patients will complain about them. Many of these phenomena are produced by shadows falling on the retina from opaque objects in the eye.

Shadows in collimated light are sharp, however near or far they are from the screen.

Place a pinhole at the anterior focal point of the eye, and opacities within the eye will cast sharp shadows, whether the objects are in the anterior or posterior region of the retina.

Features from the anterior segment appear as shadows when viewed with a pinhole at the anterior focal point of the eye. A small pinhole, a large pupil, and a very bright background will enhance the effect.
Shadows from extended sources have two components, an Umbra and a Penumbra.

Here, light from the Sun hits the Moon, which casts a shadow on the Earth. Part of the earth is inside the Umbra, and sees a total eclipse. The rest of the Earth is inside the Penumbra and sees a partial eclipse.

Inside the eye, with a large bright background like the blue sky, the pupil acts like an extended source. Objects close to the retina will generate distinct shadows because they are close enough for the umbra to hit the retina. Objects farther do not generate distinct shadows, and only reduce the overall average light hitting the retina. With a large pupil (left) the umbra is short, but with a small pupil or pinhole, the umbra extends and so objects may become visible that are inside the vitreous. Note, objects in eye are not to scale.

**Floaters, aka “muscae volitantes” (Latin for “flying bugs”)**

“Floaters are little “cobwebs” or specks that float about in your field of vision. They are small, dark, shadowy shapes that can look like spots, thread-like strands, or squiggly lines. They move as your eyes move and seem to dart away when you try to look at them directly. They do not follow your eye movements precisely, and usually drift when your eyes stop moving."

[“Facts about Floaters” https://nei.nih.gov/health/floaters/floaters]
movie “Floater_WhiteBloodCells.mp4”

https://upload.wikimedia.org/wikipedia/commons/b/b2/Floaters.png
Simulated image of floaters from the Wikimedia Commons, as they appear against a bright blue sky. Note that they sometimes do not appear in sharp focus.
**Causes of Floaters**
Primary cause is the liquefaction of the vitreous gel with aging. In particular, as the vitreous shrinks with age, it becomes detached from the retina (PVD: Posterior Vitreal Detachment), allowing a free flow of material between the vitreous gel and the retina. Collagen fibers that were part of the vitreous become loose clumps that move around as the eye moves. Other causes include material left over from the hyaloid artery that breaks down during the third trimester, and sometimes material from the retina itself that breaks off during a vitreal detachment.

**Appearance of Floaters**
When they are very close to the retina, floaters cause sharp shadows or diffraction patterns. When they are farther from the retina they produce blurry shadows and are less distinct. Shadows cast on the retina are not visible unless they move. When shadows are stationary, the retina and brain adapt to the lower light level there and the shadow is not noticed. Shadows move when a) the object moves, or b) the direction of light changes. In the case of a), rapid movement of the eye causes the vitreous body to shift, displacing the fluid between vitreous and retina. Clumps of different size move at different speeds, resulting in an appearance of objects moving across the visual field. As the eye settles down, the vitreous tends to sink, displacing the fluid and debris upward. Because the retinal image is inverted relative to gravity, the floaters appear to sink. In fact, they are moving upward. In the case of b), if a pinhole is moved across a large pupil, then many shadows on the retina become noticeable, particularly the ones caused by blood vessels. Collagen fiber clumps, “floaters”, also become more noticeable in this case.

**Awareness of Floaters:**
Although the debris are constantly present, our awareness of floaters varies depending on several things:
1) If they don’t move much, we adapt to the dimmer retinal illumination under the shadow
2) If they are in the periphery, our acuity is too low to see the diffraction pattern caused by the very small fibers.
3) High level attention mechanisms filter out the floater images because they are not part of the world “out there” that we are trying to see. As soon as someone mentions floaters, however, attention turns to them and they may become visible and annoying. This is similar to the way eyeblinks become noticeable when someone mentions them.

**Clinical significance of Floaters:**
A sudden increase in floaters may be a sign of infection, inflammation (uveitis), hemorrhaging, retinal tears, or other injury to the eye. Sufficiently dense floaters can obscure foveal vision enough to affect acuity, or may become so annoying that patients seek treatment. When a patient complains of floaters, it is important to rule out recent onset significant issues like retinal detachment, before giving assurance that they are common and benign.
**Treatment for floaters:**
Most cases are not treated. Patients are told it is a natural part of aging and there is no simple procedure to remove them. More severe cases can be treated with vitrectomy. Removal of the vitreous body resolves the floaters, but brings with it other complications like cataract and possible retinal detachment. “Floaterectomy” is a term used to describe partial vitrectomy to resolve floaters.

“Floaterectomy Versus Conventional Pars Plana Vitrectomy For Vitreous Floaters”
http://www.djo.harvard.edu/site.php?url=/physicians/oa/1004

Some doctors may try YAG laser treatment to vaporize the fibers, or enzymes to break them up.

**White Blood Cells:**
White blood cells are large enough to completely fill the small capillaries in the retina. Since they displace the smaller red blood cells, which absorb light and cast a shadow, and since they are mostly water, they make the blood vessel temporarily clear. In retinal imaging, when a white blood cell moves through we are able to see the photoreceptors behind the capillary. Visually, they may appear as small white spots moving in the visual field. This is called **Scheerer’s phenomenon.** Wikipedia has a nice simulation of how they appear against a bright sky.

https://en.wikipedia.org/wiki/Blue_field_entoptic_phenomenon
https://upload.wikimedia.org/wikipedia/commons/7/70/Blue_field_entoptic_phenomenon_animation.gif

To understand why they appear as small white spots, watch the demo **WBCsim.mp4.** Fixate the center spot until the dark band fades, and the moving gap in the band will appear as a white spot. For a more elaborate version of this, watch the demo **TroxlerDemo3Hz.mp4.** Spots move around a circle, appearing first as gaps in the ring then as objects of opposite color.

**Purkinje Tree:**
The Purkinje tree is a shadow of the superficial retinal vasculature. It is normally not visible because of adaptation and central inattention. There is also evidence of local amblyopia for cells shadowed by the blood vessels.

This figure from Adams and Horton shows that there are fewer cells in cortex devoted to the right eye in locations that are shadowed by blood vessels. Data are from a squirrel monkey.

The Purkinje tree becomes visible when the light source moves. This can be achieved by viewing with a pinhole pupil, when the natural pupil is large. Moving the pinhole across the natural pinhole makes the shadows of the vessels move enough that they become visible.

A better method to visualize the Purkinje tree is to illuminate the eye through the sclera. Place a penlight against the closed lid near the limbus and move it in small circles. This will make the shadows fall on receptors that are not usually shadowed, and the tree becomes more visible. The more pinpoint the light source, the sharper the shadows will be, and thus smaller blood vessels can be seen.
Phosphenes:

**Phosphenes** are perceived flashes of light that arise because of internal activity in the retina or higher visual system. Phosphenes can be caused by mechanical action on the retina, as occurs during vitreous detachment.

**Moore’s lightning streaks** are flashes of light that resemble lightning bolts. They usually appear in the temporal visual field, and are fairly common in middle age and older patients as they experience Posterior Vitreal Detachment (PVD). The vitreous puts traction on the retina and the mechanical action causes the cells to discharge.

**Flick Phosphenes** are produced by rapid, large, saccadic movements of the eye. They are more commonly noticed by older patients, suggesting that the partially or fully detached vitreous may be tugging and/or bumping on the retina. They are most noticeable when dark adapted.

**Pressure Phosphenes** are produced by direct mechanical stimulation of the eye. Close your eye, turn your eye toward the nose, and press on the temporal side through your lid. You will see a spot appear in your nasal visual field.

![Graph showing correlation]

From Fresco, Ophthalmology, 1998

**Electrical Phosphenes** are produced by electrical stimulation of the retina or cortex. These are sometimes noticed by subjects being fitted with EOG (ElectroOculoGram) electrodes when the impedance is being tested. Examiners run a small amount of current through the electrodes to make sure the contact is good, and this current stimulates the retina.

**Cortical Phosphenes** are likewise produced by electrical stimulation of the cortex. A new technique called Transcranial Magnetic Stimulation is gaining interest as a tool for studying cortical function, and this sometimes produces flashes of light.

Some neurologists have experimented with implanted electrode arrays on the visual cortex in order to produce phosphenes in blind patients. Stimulation electrode
arrays implanted in the eye are currently under development as well. The most advanced of these is the ARGUS II from Second Sight.


Left: A patient wearing the apparatus that records video and transmits it by radio into the implanted ARGUS II device.

Above: An image of the photoreceptor array, with a white circle to indicate the relative size of one electrode in the ARGUS II device. The spatial resolution of current implant devices is extremely poor.

In the context of Perception, the important thing about Phosphenes is that they are perceived as light, and can be used to recognize forms. This is an example of Müller's law of specific nerve energies. Activation of the optic nerve fibers is perceived as light because those nerves are associated with vision.
Migraine auras:
Migraine sufferers often experience a sensory phenomenon prior to, or in conjunction with a severe headache. These phenomena can affect any of the senses, but visual migraine auras are fairly common. The auras have been called “fortification illusions” because they appear as criss-crossed lines forming a “fence” that moves across the visual field, leaving a scotoma in its wake. The aura and scotoma are homonymous (in both eyes) because they are a cortical phenomenon. Vision usually recovers in a wave as well, a few minutes behind the slowly drifting aura. Administration of a migraine medicine (aspirine + caffeine + acetaminophen) at the onset of aura may prevent the headache.

Afterimages
Afterimages are the result of adaptation to light patterns. They are local to particular retinal areas, and so they move with the eye. They are not usually noticed because the eye is constantly moving, changing the local stimulation and thus preventing adaptation. Try [http://www.johnsadowski.com/big_spanish_castle.php](http://www.johnsadowski.com/big_spanish_castle.php)

Fixate the center black dot for about a minute, then look at the white spot. You should see a dark grid floating over the white grid. The motion you see in the afterimage is caused by your own fixation jitter. (from Dr. Bedell, source unknown).
Using afterimages to “tag” the foveas, to test for Anomalous Retinal Correspondence

In this test, each eye is flashed to put an afterimage in the middle of the fovea. With both eyes open, most people will then see the two afterimages in the same direction (upper left diagram). People with Anomalous Retinal Correspondence (ARC) do not necessarily see their two foveas as representing the same direction when both eyes are open. Even though the targets are on the foveas of both eyes, they do not perceive them as overlapping.

A bright moving light leaves a trail behind it that comes from Visual Persistence and Light Adaptation. In the sketch below, a bright green spot leaves behind a short green streak (from visible persistence) and behind that is a long lasting afterimage (from light adaptation).

Afterimages last longer if the background light changes, making it more obvious that one region of the retina is adapted differently from another. Move the eye back and forth from a bright area to a dim area, and the afterimage will keep reappearing, then fading.
Maxwell’s spot

The macular pigment overlying the fovea selectively absorbs blue light. The retinal area covered by macular pigment is roughly the same size as the foveal pit. Light comes from the bottom and passes through this pigment before reaching the photoreceptors. Under the right viewing conditions, we see a dark spot centered on the point of fixation. The spot is hard to notice because it moves with the eye and because we adapt to the difference in color/brightness.

Left image: From Snodderly 1984. Cross section of a monkey retina in the region of the fovea. The upper image was made with green light illumination, the lower image with blue light. The dark appearance in the lower image comes from the macular pigment absorbing the blue light.

Right image: Pigment absorbance vs. wavelength, with data from various studies.

Maxwell’s spot is most easily seen with alternating illumination. Try staring at the green square for a few seconds to adapt your long and middle cones, then look at the blue. You should see a dark spot in the area around your fixation point. The spot is usually a little bigger than your thumb at arms length.

Maxwell’s spot is sometimes used to diagnose eccentric fixation. If a patient sees the spot off center from the point of fixation, it indicates they are not using the central fovea for fixation.

A similar technique uses Haidinger’s brushes. These refer to a windmill pattern that appears when viewing polarized blue light. If the windmill is not centered on the fixation point, it indicates eccentric fixation.