The Case of the Oversized Planet

Illusions noticed by Galileo can help explain how we see light and dark

From Earth, Venus (*center*) appears larger than Jupiter (*far left*) because of an intriguing optical effect. The moon, viewed the same night, has been added to this image for scale.

Galileo Galilei was puzzled. The Renaissance-era astronomer had noticed that planets appeared to expand with a "radiant crown" when viewed with the naked eye—but the effect was greatly diminished when viewed through a telescope.

The discrepancy led him to wonder: Was this size illusion caused by moisture on the cornea? Light scatter? Neither possibility satisfied because these effects would persist even if one used a telescope. In fact, Galileo had hit on a visual riddle that researchers are still unraveling.

One clue came from the observations of another luminary: artist and engineer Leonardo da Vinci. Just decades before Galileo's discovery of the radiant crowns, Leonardo had noted that dark objects on a light canvas seemed more defined than light objects on a dark background. Vision scientists since have found that a white shape on a black background often appears larger than an equally sized dark object on a light background. An explanation for these peculiar perceptual patterns arrived in the 19th century, when Hermann von Helmholtz, the venerable German physicist and physiologist, determined that there were at least two contributors to this effect, which he dubbed the "irradiation illusion."

The first contributor results from the way light scatters in the eye. When we look at a very bright object, photons pass through the retina, and some are absorbed by photoreceptors, creating focused vision. Unabsorbed photons can then reflect off the back of the eye behind the retina and disperse as they reflect back through the retina, resulting in scattered, unfocused activation of a larger patch of photoreceptors. This phenomenon is called entoptic glare.

This optical effect helps to explain not only Galileo's radiant crowns but also why Jupiter, our solar system's largest planet, appears smaller than Venus. Technically, both astronomical bodies are so far away that their photons subtend an area smaller than a single photoreceptor in an Earth-bound human's retina. In fact, depending on the time of year, the planets should appear between nine and 66 arcseconds across—visual distances so small to the naked eye that a person with 20/20 vision would only perceive them as about one arcminute each. (To illustrate how small that is: if you painted your thumbnail with 60 alternating black and white vertical stripes and held it at arm's length, each stripe would be about one arcminute wide.) Because Venus is closer to the sun and to Earth, its surface reflects significantly more photons into your eyes than does Jupiter's, causing greater entoptic glare.

But a second contributor is also in play in the irradiation illusion. Glare could not explain, for example, the fact that Galilean moons appear smaller when seen as black dots against Jupiter's mass than when seen as white beacons against the night sky. The answer, von Helmholtz realized, must reside in how the brain processes light versus dark objects. Scientists are only now finding ways to elucidate these neural processes.

As the examples in this column illustrate, the interplay between light and dark is critical not only to stargazing but to our everyday vision because contrast is fundamental to how we see everything. M

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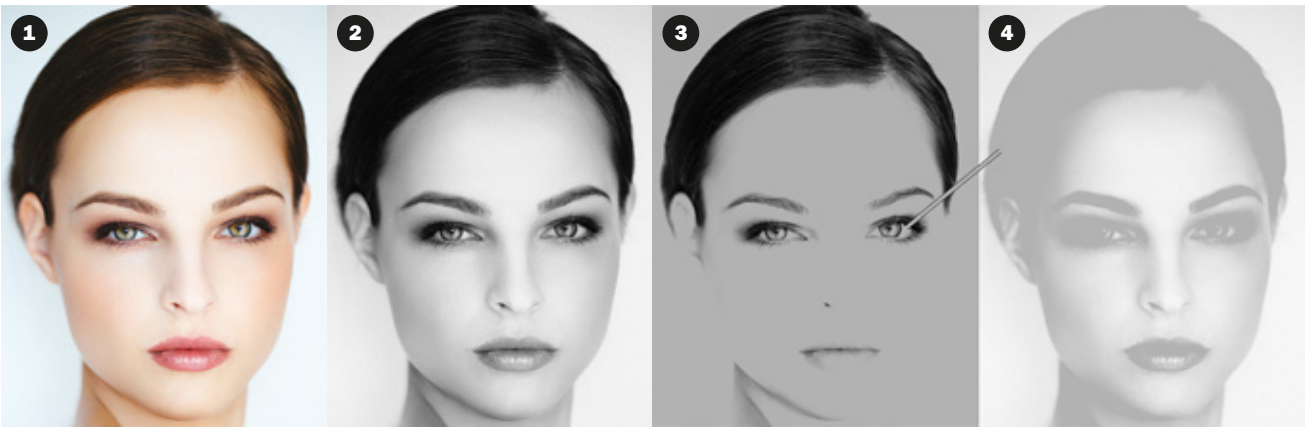
CONTRAST VS. DETAIL

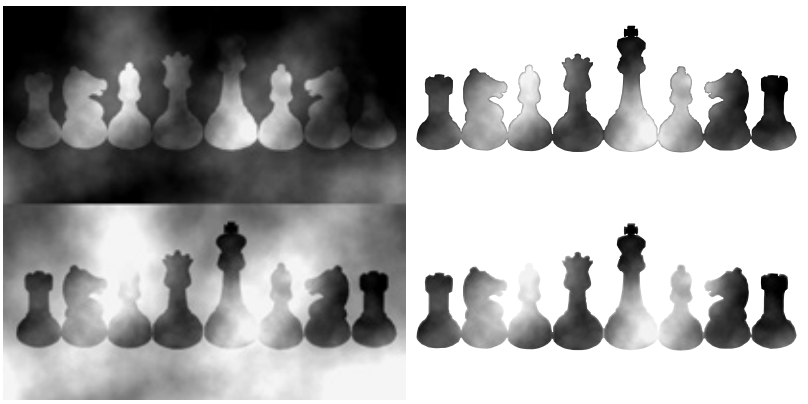


New discoveries help to show how neural processing in the visual system results in light objects looking larger than dark objects. These findings—from the laboratories of Jose-Manuel Alonso of the State University of New York College of Optometry and David Fitzpatrick of the Max Planck Florida Institute for Neuroscience—explain not only much of Galileo's puzzling observations but also the ways we experience contrast itself.

The series of face images here, by Alonso, demonstrate how light versus dark processing plays out in our everyday vision. In image 1, we have a normal color photograph. In image 2, we see it in gray scale. Interesting things start to happen if we view solely the pixels that are dark in the image (less than the median brightness of the image) versus those that are light (the brighter 50 percent of the pixels).

Notice how sharp and precise the dark-pixels version is (*3*). This observation follows from the discovery that the neural system that processes darks does so with high resolution and precise spatial detail. In the light-pixels image (*4*), the perception of contrast is strong, but detail is lost. Alonso's illusion won placement as a top-10 finalist in the 2016 Best Illusion of the Year Contest.

The researchers found that light-processing neurons receive input from larger areas of the visual scene (and therefore have lower resolution) than dark-processing neurons (which thus have higher resolution). In normal vision, the dark- and light-processing systems work together to create contrast, which gives rise to powerful effects. For example, the whites of the eyes in the dark-pixels image appear to be much lighter than the hair in the light-pixels image, and yet if we connect the two with a strip that matches their color, we can see that they are actually identical. (Remember: the lightest pixels in the dark image are the same shade as the darkest pixels in the light image—both equal the median brightness of the normal grayscale image.) This suggests that any difference in perceived detail or contrast must be caused by how the brain processes lights versus darks.



BLACK AND WHITE AS EQUIVALENT

Barton L. Anderson, now at the University of Sydney in Australia, and Jonathan Winawer, now at New York University, have pushed to the limit the remarkable fact that a gray surface can look light or dark depending on its context. The chess pieces above and below are identical, but the variations in the surrounding clouds make us perceive the upper pieces as white and the lower ones as black. Removing the cloudy background (*comparison at right*) eliminates the illusion. Checkmate!

MORE TO EXPLORE

- **Image Segmentation and Lightness Perception.** Barton L. Anderson and Jonathan Winawer in *Nature,* Vol. 434, pages 79–83; March 3, 2005.
- **Neuronal Nonlinearity Explains Greater Visual Spatial Resolution for Darks Than Lights.** Jens Kremkow et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 111, No. 8, pages 3170–3175; February 25, 2014.
- **Topology of ON and OFF Inputs in Visual Cortex Enables an Invariant Columnar Architecture.** Kuo-Sheng Lee et al. in *Nature,* Vol. 533, pages 90–94; May 5, 2016.
- Jose-Manuel Alonso's top-10-finalist entry, 2016 Best Illusion of the Year Contest: **http://illusionoftheyear.com/2016/06/lights-and-darks-in-vision**

GETTY IMAGES (*woman*); JOSE-MANUEL ALONSO (*face series*); FROM "IMAGE SEGMENTATION AND LIGHTNESS PERCEPTION," BY BARTON L. ANDERSON AND JONATHAN WINAWER, IN *NATURE*, VOL. 434; MARCH 3, 2005 (*chess pieces*)