# The world is full of darkness, reflected in the physiology of the human retina, researchers say

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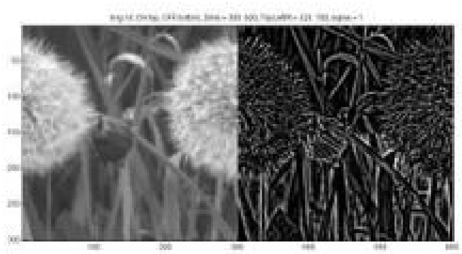

Image of dandelions rectified into separate channels for bright (ON) and dark (OFF) contrasts. More intense pixels correspond to stronger contrasts. Following rectification, highlights appear bright in the ON image and dark in the OFF image. Credit: University of Pennsylvania

Physicists and neuroscientists from the University of Pennsylvania have linked the cell structure of the retina to the light and dark contrasts of the natural world, demonstrating the likelihood that the neural pathways humans use for seeing are adapted to best capture the world around us.

Researchers found that retinal ganglion cells that see darkness are more numerous and cluster closer together than those that see light, corresponding to the fact that the natural world contains more dark spots than light. Now physicists, and not just pessimists, see the world for the dark place it is.

The results suggest that the brain's separation of retinal circuitry into off and on mosaics that separately process dark and bright spots allows for structural adaptation to the natural scenes humans must see.

The team took the study a step further by constructing artificial images that matched the characteristics of the natural world and by testing what sorts of off and on mosaics best represented information from these images. According to the authors, the total flow of information peaked for mosaics with more densely clustered off cells, as in the human retina, suggesting that human vision has evolved to efficiently represent visual information in the natural world.

Researchers looked at the physiology of the retinal ganglion cells whose job it is to respond to a dark spot on a brighter background, simply called off cells, wondering why the brain would have clusters of off cells and not an even distribution across the retina. In addition to being more numerous and branching together in dense, bushy clusters, they also have smaller dendritic fields than the cells responsible for seeing light spots. By branching together more densely in clusters, they collect more synapses per visual angle. Thus, researchers concluded that the retina devotes more resources to processing dark contrasts, a natural capability reflected in the fact that there is more dark information in the world around us.

Researchers tested the hypothesis by measuring the spatial contrasts in natural images and quantifying the distribution of lightness and darkness. At all scales, the authors found that natural images contain relatively more dark contrasts than light.

"Photoreceptors respond to light," Vijay Balasubramanian, professor of physics and the study's lead author, said. "But a couple of layers deeper down in the retina, cells are responding to changes and differences in the amount of light across the image. The eye is not a digital camera, recording little pixels. The eye doesn't do that. The eye tells the brain that there are differences in light between neighboring points. The brain learns about contrast. And in this case, there is about twice as much brain activity responding to darker spots."

The team confirmed this across a range of spatial scales and traced the origin of this phenomenon to the statistical structure of natural scenes. Researchers showed that the optimal mosaics for encoding natural images are also asymmetric, with off elements smaller and more numerous, thus matching retinal structure. Finally, the concentration of synapses within a dendritic field matches the information content, suggesting a simple principle to connect a concrete fact of neuroanatomy with the abstract concept of "information": equal synapses for equal bits.

Researchers were interested in how the visual system is adapted to the physical structure of the world, an assumption that makes sense from an evolutionary standpoint. The physics of the natural world should correspond to the processing capabilities of the brain and there are many observable incidences of this phenomenon in the human and animal world. For example, frogs eat flies. That fact predicted that frog's eye contains "fly detectors." Flies, in turn, track potential mates in mid-air, predicting specialized neural fly circuits that detect other flies.

This study demonstrates the opposite case. Here, a particular feature of the human neural circuitry predicted a surprising property of the visual environment.

The study, published in the *Proceedings of the National Academy of Sciences.*

Provided by University of Pennsylvania