Light is necessary for life, but increasing exposure to artificial light may be detrimental to human health. With prevalent use of light-emitting diodes (LEDs) in ambient lighting and electronic devices, humans are increasingly exposed to blue light that appears white due to addition of other colours. Excessive blue light can damage eyes, but it is not known whether daily LED exposure across lifespan may have other adverse health effects. A recent study in short-lived model organism *Drosophila melanogaster* revealed that cumulative, long-term exposure to blue light impacts brain function, accelerates the aging process and significantly shortens lifespan compared to flies maintained in constant darkness or in white light with blue wavelengths blocked. Increased mortality and brain neurodegeneration was also observed in flies with genetically ablated eyes, demonstrating damage to non-retinal cells. As molecular responses to light are similar in the cells of both fruit flies and humans, these studies suggest that lifelong daily blue light exposure may impair cellular health in humans.

### How organisms sense light

Life on Earth evolved in endless cycles of sunlight and darkness generated by the daily rotation on the planet’s axis. All photosynthetic organisms for which light is a fundamental source of energy developed sophisticated mechanisms to sense sunlight intensity and direction. Light is also an environmental stimulus of primary importance for all life forms including unicellular microorganisms (bacteria, algae and protozoa), fungi, plants and animals. Light–dark cycles synchronize cellular processes from gene expression to metabolism. Animal behaviour is profoundly impacted by the presence or absence of light, dividing them into diurnal, nocturnal or crepuscular creatures occupying different time-of-day niches. Light sensing is accomplished by specialized light-detecting molecules (chromophores); when activated by light of a specific colour, these molecules interact with specialized proteins, which change their shape and turn on signalling pathways in photoreceptive cells. Two major chromophores detecting blue light predominate in all life forms: vitamin B2-derived flavins (especially flavin adenine dinucleotide [FAD]), which interact with proteins such as cryptochromes involved in many processes requiring light detection, and vitamin A-derived retinols, which interact with a single family of proteins called the opsins (also known as rhodopsin). Opsins are responsible for all visual processes by turning on signalling pathways in photoreceptor cells (rods and cones in our eyes) that ultimately send a message to the brain about the quality and direction of light resulting in image forming. There is another class of opsin proteins that are not involved in conscious vision, but rather in non-visual light signalling. They are called the melanopsins and are present in the nervous system and other tissues of both vertebrates and invertebrates.

### From sunlight to light-emitting diodes

All photoreceptive systems serving both non-visual and visual functions evolved in the presence of and in response to natural sunlight. That is, until our human ancestors learned how to make and use fire to illuminate darkness after sunset. Over the centuries, humans created portable light by burning natural fuels. In ancient China, natural gas trapped from volcanoes was transported in bamboo pipes and used to light up cities. Other sources of light used in the ancient world and that persist in the modern times are oil lamps and candles. Over 200 years ago, the first carbon arc lamp was created, demonstrating that electricity could be harnessed as a source of light. This event gave rise to a stream of technological advances that created incandescent and fluorescent bulbs, halogen lamps and, finally, light-emitting diodes (LEDs). Since the introduction of the first LED screw-in bulb for general use in 2011, LEDs are becoming ubiquitous in homes and public places alike. Following the miniaturization of electronics, LED has become a critical component of electronics with display screens: phones, laptops, desktops, TV, etc. Indeed, humans have become awash in LEDs for most of their waking hours. Compared with traditional artificial light sources, LEDs have higher luminous flux, lower power consumption, longer life span and a choice of colours. While LED light has so many advantages, it has a dark side that is becoming a major health issue. Most LED sources predominantly emit light in the blue spectrum with a peak at approximately 450 nm; it appears white due to the addition of yellow fluorescent powder, which is activated by blue light. While the spectrum of natural sunlight is spread out across all visible wavelengths, the spectrum of commonly used cool white LED is dominated by blue light with a second broader peak at 550 nm (Figure 1). The energy carried by photons corresponds to its light colour, such that blue light with wavelengths between 400 and
500 nm carries much more energy than the warmer light colours. Thus, we need to keep in mind that a typical cool white LED contains much higher proportion of blue light than sunlight.

**The effects of acute blue light on eyes**

The human eye is a sophisticated organ conveying precise visual information with incredible speed and acuity and translating it into neural signals in a process called phototransduction. Eyes are able to detect even very dim light due to a tight packing of opsin molecules in extensive membranes of photoreceptor cells (rods and cones). But the downside of this high sensitivity is that excessive exposure to light can be very damaging to the eyes. Studies in animal models have shown that exposure to blue light may be a risk for the development of retinal pathologies, especially age-related macular degeneration (AMD). Many retina-derived cell types can be maintained in culture, and experiments have shown that exposure of these cells to blue light causes accumulation of reactive oxygen species (ROS), which damage the mitochondria and other cell structures, leading to cell death. Effects of blue light on eyes are also investigated in *Drosophila melanogaster*. In keeping with other insects, *Drosophila* have compound eyes consisting of hundreds of light-focusing and processing units called ommatidia (Figure 1). Although fly eyes are externally very different, membranes of photoreceptors cells are tightly packed with opsin molecules just like in the human rods and cones, making them a good model organism to study the damaging effects of light at a fundamental biochemical level. Indeed, when flies are exposed to even a few hours of intense blue light, photoreceptor cells in their eyes produce ROS and begin to degenerate. Researchers measured gene expression changes in fly retina under these phototoxic conditions and determined that genes involved in stress response pathways were up-regulated while those encoding components of phototransduction pathways were reduced. Experiments on model organisms, such as the fly, will likely help to understand the molecular basis of phototoxic effects of blue light on human eyes.

**Daily dose of blue light accelerates aging in *Drosophila***

With a widespread use of LEDs in ambient lighting and electronic devices, humans are increasingly exposed to blue light; however, as the LED technologies are relatively new, the long-term effects of daily exposure to blue light across human lifespan are not known. We enlisted fruit flies to address this question. The lifespan of *Drosophila* is approximately 70 days; so, 1 day in the life of a fruit fly corresponds to about 1 year of life for humans. Adult flies were maintained in daily cycles of 12-hour blue LED and 12-hour darkness or 12 hours of white light with blue wavelengths blocked, while control flies were kept in constant darkness. Flies exposed daily to blue light showed significantly reduced longevity compared to flies in constant darkness, while longevity of flies in white light was not affected. As it is known that blue light induces retinal degeneration, longevity was also measured in flies with genetically ablated eyes to exclude the direct effects of eye damage on fly survival. Importantly, the lifespan of eyeless flies was shortened in a similar way as the lifespan of wild-type flies (Figure 2), suggesting that compromised longevity is not caused by retinal degeneration. What then could contribute to reduced longevity in flies exposed daily to
blue light? Experiments revealed that both wild-type and eyeless flies had increased brain neurodegeneration and impaired locomotion (Figure 3), suggesting that these conditions lead to accelerated aging. The effect is specific to blue wavelength because flies exposed to white light of the same photon flux density, but with blue part of the spectrum blocked, do not show these phenotypes.

**Human relevance**

While there are many published reports on the effects of acute blue light on the retina, there is a need to investigate the effects of daily non-acute exposure on long-term organismal physiology and aging. It appears that, at least in flies, brain and locomotor impairments do not depend on the damaging effects of light on the retina, as these phenotypes were evident under blue light in flies with genetically ablated eyes. Apparently, blue light can directly affect non-retinal cells that are not specialized in image-forming phototransduction. It is known that a special type of blue-sensitive opsin, called melanopsin, is widespread in vertebrates and is present in several types of human cells including skin, fat and blood vessels. Opsins are also expressed in non-retinal cells of flies, and further studies should explore the role of this opsin in response to chronic blue light exposure.

**Figure 2.** Daily exposure to 12 hours of blue light dramatically shortens the lifespan in both wild-type and eyeless flies. In contrast, the longevity of flies exposed daily to white light of the same intensity, but with blue wavelengths filtered out, was similar to that of flies kept in constant darkness.

**Figure 3.** Flies exposed daily to blue light show greater signs of aging. Their brains display dark vacuoles in places where neuronal death occurred (marked by red arrows). Increased brain degeneration is associated with impaired locomotor abilities as blue light–exposed flies show reduced ability to climb up the walls of test vials compared to dark-reared flies (significant differences marked by the asterisks).
Another important question that awaits addressing is what other molecules are involved in mediating phototoxicity. Unexpectedly, dramatic effects of blue light on fly aging establish them as a model in which to investigate long-term cumulative effects of light at the cellular and organismal levels (Figure 4).

Figure 4. Experiments on flies exposed to blue light may have clinical relevance. They should help to understand which molecular pathways are affected by blue light–carrying photons of high energy. Understanding the biochemistry of phototoxicity could help in the future to protect human cells from the damage that may be caused by excessive light exposure.

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