EC OPHTHALMOLOGY
Review Article

Root Cause of Myopia and Best Lamp for Vision

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Abstract

The article analyzed the factors induced myopia: inheritance and environment.

Flicker in the Environmental effect is the dominant factor. Flicker will cause eyestrain, long term eyestrain will cause the ciliary muscle to contract and never relax, then the lens shape becomes rounder and cannot focus the distant object on the retina. The myopia is induced.

Percent flicker and flicker index are used to measure the flicker.

When percent flicker and flicker index are smaller, the flicker is smaller, then the flicker above the retina comfortable level is smaller, the accumulated uncomfortable light energy needs more time to reach the pupil shut threshold, the pupils dilate and contract less, so the eyestrain is reduced.

Current lamp manufacture did not remove flicker but tried to increase the flicker frequency to kilohertz and above in order to fool the eye not to sense the flicker. The analysis proves high frequency flicker does not reduce the eyestrain.

For best lamp, we need the lamp absolutely flicker free that is Percent flicker = 0% and Flicker Index = 0. Spectrum of the light is also related to eyes health, analysis is done to show the spectral components' impact.

Keywords: *Myopia; Lamp; Vision; Percent Flicker; Flicker Index*

Myopia is only determined by genetic factors?

According to research by the National Institutes of Health, currently more and more people are getting myopia, or shortsightedness, and the frequency of cases are expected to rise throughout 2050. Why is this the case?

For every decade passed, there is an increase of 5% more cases of myopia, and research predicts that one out of two people will be shortsighted by 2050. If the main reason for this increase was genetic inheritance, the percentage cases should remain relatively static over time. However, figure 1 illustrates that the prevalence of myopia is increasing linearly over the years. The most logical conclusion drawn from this trend is that main factor of myopia is not related to genetic factors. What are the main factors?

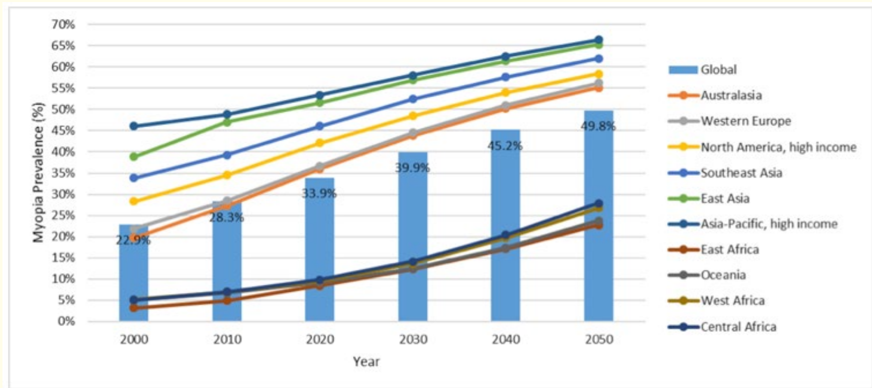


Figure 1: *Graph showing global burden of disease (GBD) regions with estimated high (> 55%) and low (< 30%) myopia prevalence by 2050 [1].*

One of which is years of education, which in figure 2 shows that cases of myopia are directly correlated with subjects' years of education.

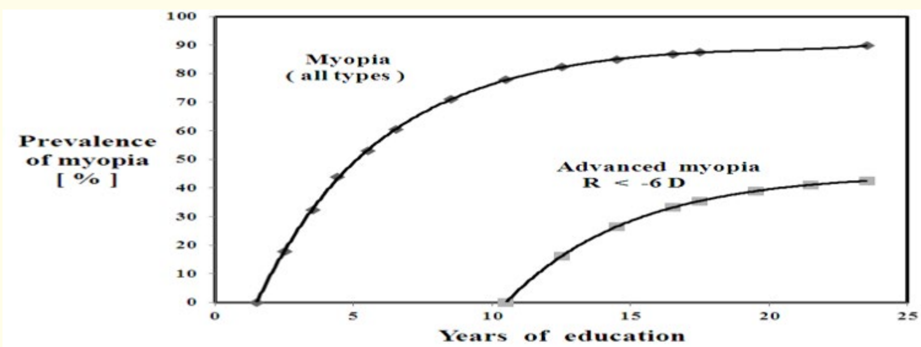


Figure 2: *Prevalence of myopia with years of education [2].*

As the years of education increased, so did the prevalence of myopia cases, the reason being that students are required to spend large amounts of time studying under artificial light and on screens. One characteristic that artificial light and digital screens share is flicker, which causes significant eyestrain. To understand why, we need to understand the structure and function of the eye itself.

What is eye structure for normal eyesight?

Ideal vision requires the eye to focus when looking to both near and far objects. We are able to do so because the lenses in our eyes can be adjusted by the ciliary muscles to focus the image on the retina clearly. In the case of normal eyesight, the lens can become thinner for distance vision and rounder for nearer vision. Because of this flexibility, people can see clearly regardless of the object's far or near distance.

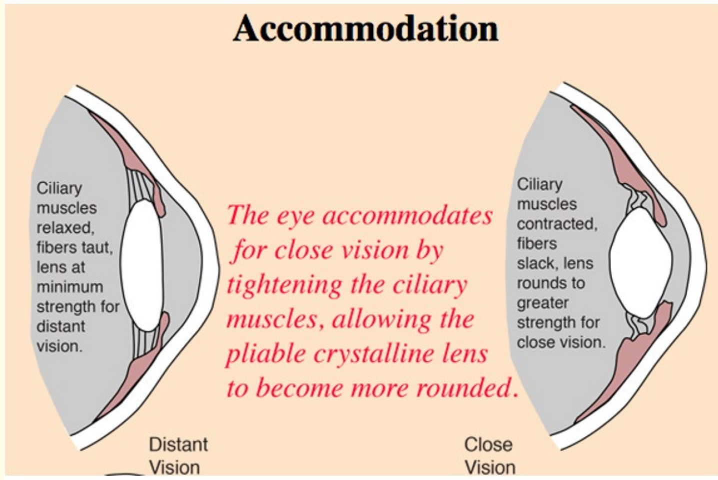


Figure 3: *For distant vision, ciliary muscles relaxed and lens is thinner or flattened; For close vision, ciliary muscles contracted, the lens is rounder or accommodated [3].*

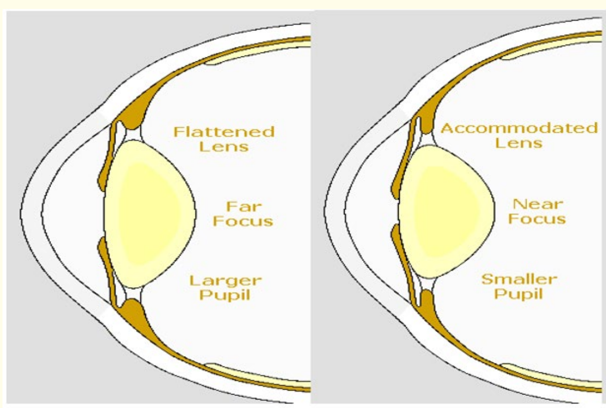


Figure 4: *For far focus, pupil is larger when lens is flattened (thinner); For near focus, pupil is smaller when lens is accommodated (rounder) [4].*

Pupil constriction and lens accommodation for focus

This adjustment in lens shape, to focus at various distances, is referred to as "accommodation" or the "accommodative process" and is associated with a concurrent constriction (decrease in size) of the pupil. [5]. During the accommodation reflex, the pupil constricts to increase the depth of focus of the eye by blocking the light scattered by the periphery of the cornea. The lens then increases its curvature to become more biconvex, thus increasing refractive power. The ciliary muscles are responsible for the lens accommodation response [6]. The ciliary muscles that control the pupil size also affect the lenses, as when the ciliary muscles contract, the pupils become smaller and the lens bulges out more; when the ciliary muscles relax, the pupils become larger and the lenses flatten. The image below illustrates the above description of lens accommodation [7].

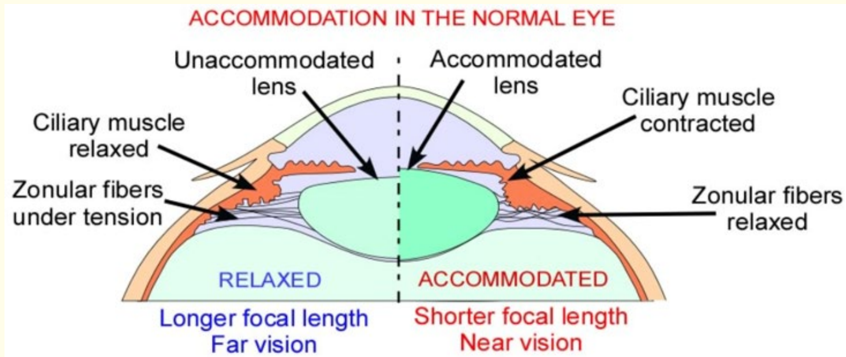


Figure 5: *Pupils size related to lens.*

Object distance	Ciliary muscle	Suspensory Ligament fiber	Lens shape	Light refracted	Pupil size
Far	Relaxes	Tight	Thinner	Less	Bigger
Near	Contracts	Slacken	Rounder	More	Smaller

Figure A

Pupil contract as lens bulges out more for near vision pupil open wider as lens flatten for far vision.

What eyes structure is for myopia?

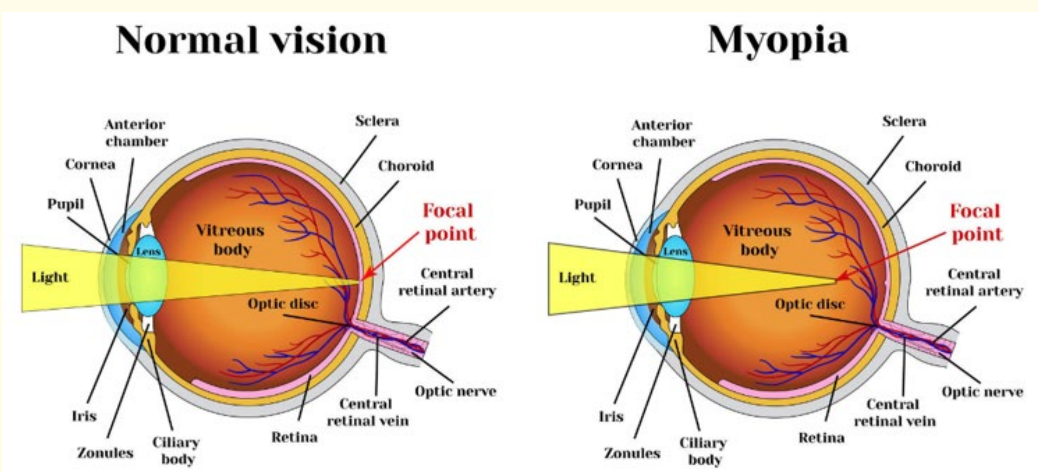


Figure 6: *Eye structure with normal vision vs. myopia [8].*

Myopia is characterized by the inability of ciliary muscles to relax and thin out the lens when seeing distant objects. Chronically tense ciliary muscles cause the focal point of light to be too far in front of the retina rather than focusing directly on it, which results in blurry vision.

There are steps in the progression of the disease, starting out with pseudomyopia which can progress to permanent myopia if left unaddressed.

First step: Pseudomyopia

Pseudo myopia refers to an intermittent and temporary shift in refractive error of the eye towards myopia, in which the focusing of light in front of the retina is due to a transient spasm of the ciliary muscle causing an increase in the refractive power of the eye.

Pseudomyopia may be either organic, through stimulation of the parasympathetic nervous system, or functional in origin, through eye strain or fatigue of ocular systems.

It is common in young adults who have active accommodation, and classically occurs after a change in visual requirements, such as students preparing for an exam, or a change in occupation [9].

Second step: Permanent myopia

If eye strain and ocular fatigue are reduced during the stage of pseudomyopia, eyesight may return to normal. However, if the ciliary muscles continue to stay chronically contracted, pseudomyopia can progress into permanent myopia. Potentially poor contractility, of ciliary muscle which may result in the development and progression of myopia [10]. The first thing that happens in this process is called ciliary myopia. When we focus on something up close, the tiny muscles in the eye that do the actual focusing of the lens have to work hard. Then, when we keep that same focus for a long time, those muscles are not allowed to rest. The eyes are not adapted to keep a close focus for a long time. As a result, the ciliary muscles become unable to relax at any time (muscle spasm, in medical terms). [11]. According to surveys by the Japanese Ministry of Education, Science, Sports and Culture, continuous ciliary contraction is correlated with late-onset myopia [12]. The ciliary contraction without relax is the root cause of myopia.

Commonly, minus lenses are prescribed for a person with myopia, even in the initial stages, enabling him/her to see clearly far away. However, when these glasses are worn to do near work, they increase the amount of near point stress, since the eyes already have attempted to adapt to a near distance without the glasses. Thus, if the person wears the new glasses (which focus the eyes at a far distance) while doing all near work, it actually can accelerate the progression of the myopia [5].

When we wear glasses, the focal point in the eye moves further back in the eye. The muscles are still straining to get focus. So the eye continues to grow longer. And we have to use stronger and stronger lenses in our glasses to compensate, making the myopia worse and worse. What started at a low 1 prescription always seems to be at 4 or 5 a few years later [11].

Pupils and flicker

The pupil constricts in bright light and dilates in dim light respectively, in other words, variation in light brightness will cause the ciliary muscles to change the size of the pupil accordingly. The type of light variation our eyes are familiar with nowadays is flicker, because electronic screens and most artificial light sources constantly expose our eyes to flicker.

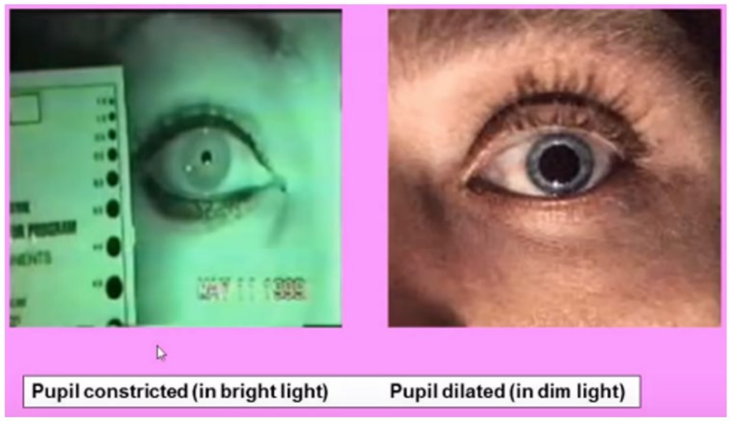


Figure 7: *Flicker impact: Pupil constricted in bright light; Pupil dilated in dim light.*

Impact of flicker

Flicker is the rapid change in light brightness over short time periods. It is present in all artificial light including electronic devices and lamps.

Because flicker happens so fast, we are not conscious of it, but long-term exposure to flicker can have catastrophic effects on eyesight. The retina has a threshold for the safe accumulated amount and intensity of light, and the pupil controls the amount of light that enters the eye to avoid retinal damage. When light hits the eye, the pupil will shut or open according to the accumulated intensity. If the light is too bright, the pupil will shut down to avoid strong radiation on the retina. When the surroundings are dim, the pupil will open wider to collect more light.

In the case of flicker, the brightness of light oscillates rapidly with time, going from strong to weak and back. The ciliary muscles that control the pupil will dilate and close intermittently to compensate for the change of lighting. As the eye is exposed to flicker for longer, ciliary muscles become more exhausted and lose their ability to contract and dilate, resulting in the inability to flatten the lens, which is what myopia is characterized by. In other words, constant exposure to flicker causes the ciliary muscles to stay in a tense position for long periods of time, which reduces their elasticity and renders them unable to adjust the lenses to focus on faraway objects.

Medical research on flicker

Many medical research papers around the world have been written on flicker induced myopia and asthenopia (eyestrain):

- Department of ophthalmology, Affiliated Hospital of Nantong University in China, research proved myopia can be induced by flicker light in B6 mice [13].
- La Trobe University, Melbourne, Australia, the experiment showed frequency temporal modulation of light promotes a myopic shift [14].
- Department of Ophthalmology, Jinshan Hospital of Fudan University in China, research result: myopia is induced by flickering light in guinea pigs [15].

If the eye was continuously subjected to such a condition for an extended time period, near-point asthenopia can promote progressive myopia [16].

IEEE research: LED Lighting Flicker and Potential Health Concerns: invisible flicker (>70Hz) health effects have been reported to include headaches and eyestrain [17].

St Erik's Eye Hospital, Stockholm, Sweden found Asthenopia (eyestrain) is significantly associated with uncorrected visual acuity and with myopia [18].

Eyestrain caused by flicker can induce myopia as well as worsen it by increasing the refraction of the lens to focus harder when the function of the ciliary muscles is already compromised.

In 'Occupational Ophthalmopathy' on Med Tr Prom Ekol. 1995;(4):14-6, The authors (which authors) describe a syndrome diagnosed in workers who perform tasks requiring visual strain. This syndrome comprises of worsened visual control, discomfort in the orbital area, and characteristic changes of refraction and accommodation. Across age groups, younger people with emmetropia and myopia demonstrate temporary and later consistent increase of refraction (myopia worsen) and the elderly ones showed decreased refraction and early development of presbyopia [19] which further proves that flicker induced eyestrain will cause and worsen myopia.

How to detect flicker?

Detecting flicker using an old cell phone

The following images are close-up photos of different light sources taken with an old cell phone-Iphone 2.

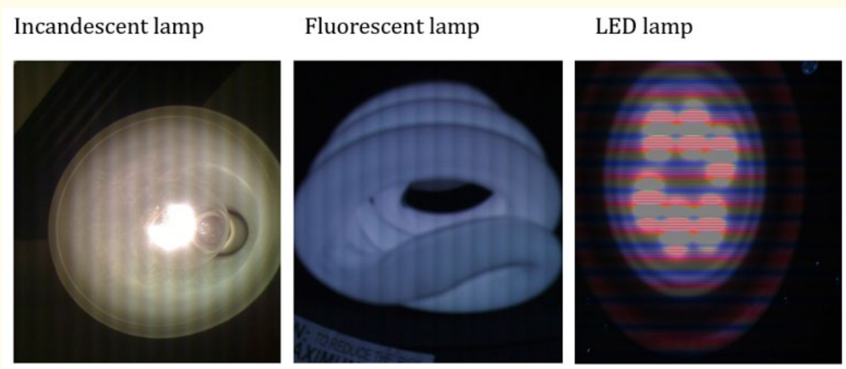


Figure 8: *Photo of incandescent lamp (left), fluorescent lamp (middle), LED lamp (right) taken by iPhone2.*

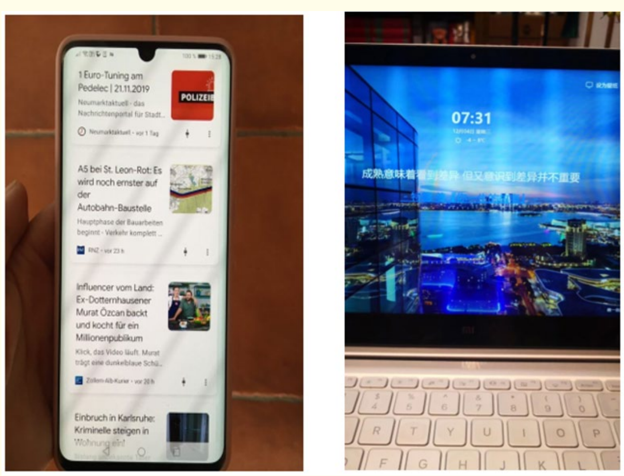


Figure 9: *Photo of smart phone and notebook computer taken by iPhone 2.*

If there are stripes on the photo, there is a flicker.

Because the light from the lamp is actually going on and off or bright and dim in a fast rate, faster than you can perceive. In space, the light waves travel in alternating patterns of light and dark. A camera sample the light for only brief milliseconds. So the alternating patterns of light and dark is shown as stripes of light and dark on the camera.

Do no stripes mean no flicker?

No. The camera photo with stripes can prove that there is flicker but the camera photo without stripes cannot prove the absence of flicker because it cannot detect high frequency flicker above a few kilohertz, where the stripes are so dense it overlaps together. Also, newer phones have an anti-shake function where the camera takes several photos and average the pixels, which cancels out the present stripes.

Technical test for flicker

The oscilloscope catches everything the phone camera may miss. you can use the oscilloscope to measure the voltage across the lamp at AC coupling with 10 mv per division, if there is a ripple voltage as shown by figure (voltage variation), flicker is present.

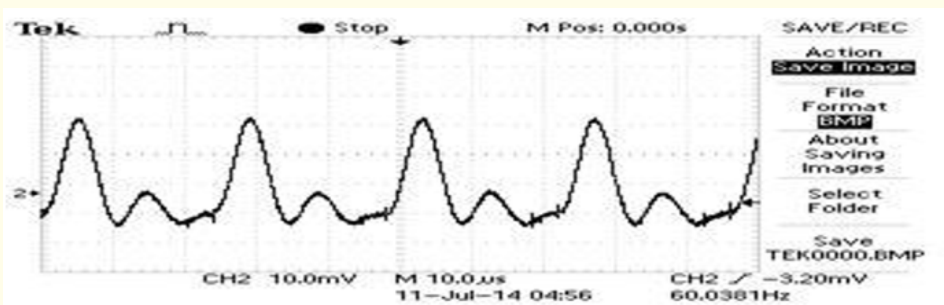


Figure 10: *AC voltage waveform across a LED lamp on the market named 'flicker free' has 25 mili-volt peak to peak voltage with 25 us period that shows there is a high frequency flicker with frequency=1/25us=40 kilohertz.*

The index to measure magnitude and degree of the flicker defined by ENERGY STAR is the official measurements of relative light output waveforms, shown in the figure below.

The higher the Percent Flicker and Flicker Index are, the more flicker there is. Likewise, having Percent Flicker = 0 and Flicker Index = 0 means that there is absolutely no flicker.

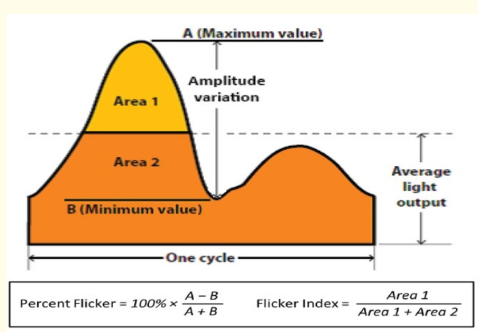
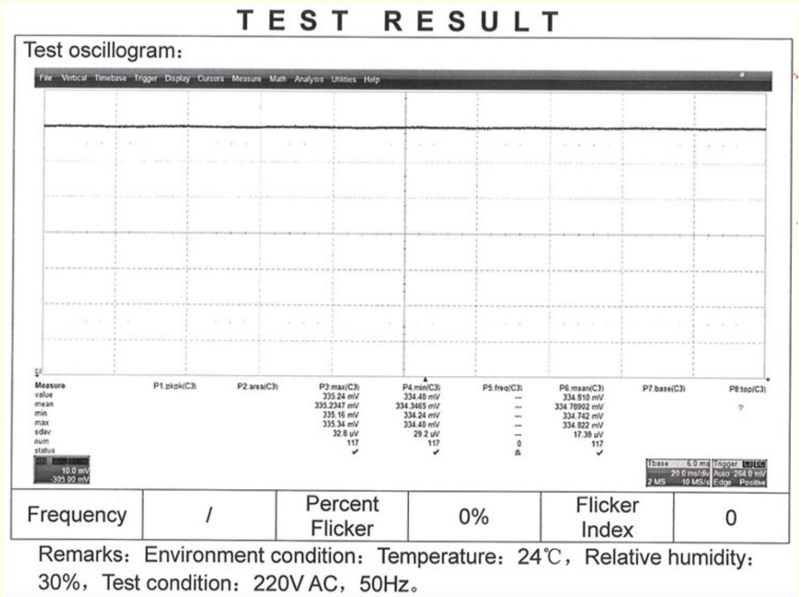


Figure 11: *Percent flicker and flicker index definition by energy star.*



TEST RESULT

Test oscillogram:

Frequency	/	Percent Flicker	0%	Flicker Index	0

Remarks: Environment condition: Temperature: 24℃, Relative humidity: 30%, Test condition: 220V AC, 50Hz.

Figure 12: *Test result of a lamp of Bright Quantum LLC (previous name was Upright Lighting LLC) from National Lighting test center showed Percent Flicker=0% and Flicker Index=0. The test result is from a test report on the website www.uprlt.com That is not impossible to achieve, as Bright Quantum LLC (previously name as Upright Lighting LLC) in U.S. has a patent US 10470260B1 that realize 0 flicker with Percent Flicker = 0 and Flicker Index = 0. The patent detail can be found on 'www.uprlt.com'.*

Where does the flicker come from? – Voltage variation

All traditional light sources have brightness variation over time as a result of voltage variation over time and when graphed it looks like a sinusoidal wave, flicker is proportional to the voltage, so the voltage waveform is similar to flicker.

Incandescent lamp is the lamp which uses lamp filament to generate light

Incandescent lamps use a 60Hz, 110v AC (alternating current) voltage as a power supply. When the voltage reaches the peaks, the light is at its brightest; when the voltage crosses the 0 point, the light is darkest. This varying brightness over time is exactly what flicker is, which is represented visually by the figure below.

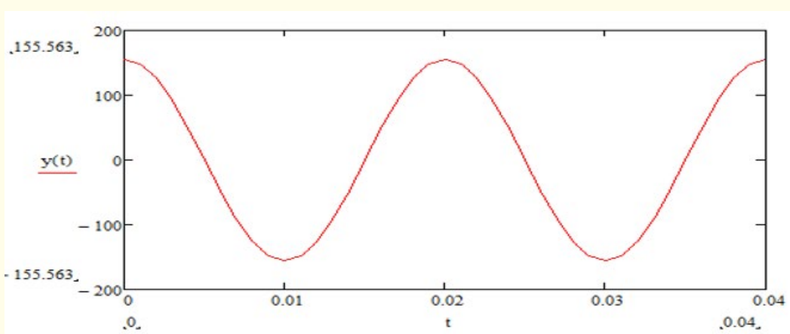


Figure 13: *Voltage waveform for 110 volt AC voltage with 60 Hertz. Incandescent lamp has percent flicker 5.1% according to [20].*

A fluorescent lamp generates light from collisions in a hot gas ('plasma') of free accelerated electrons with atoms - typically mercury - in which electrons are bumped up to higher energy levels and then fall back while emitting at two UV emission lines (254 nm and 185 nm). The thus created UV radiation is then converted into visible light by UV excitation of a fluorescent coating on the glass envelope of the lamp. The chemical composition of this coating is selected to emit in a desired spectrum.

Fluorescent lamp with electronic ballast uses 110v AC voltage with frequency above 1 kilohertz, as a power supply, and similarly to the incandescent, when voltage reaches the peaks, the light is at its brightest and when the voltage crosses the 0, the light is darkest. By the same process, the conclusion is that flicker is likewise present in voltage waveform of a fluorescent lamp voltage sources.

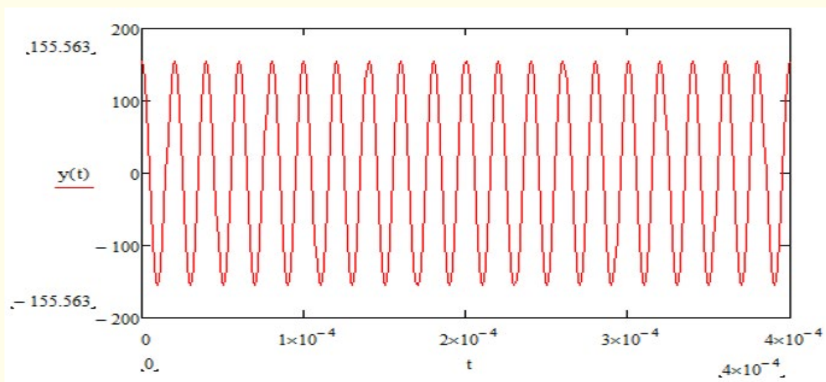


Figure 14: *Voltage waveform for 110 volt AC voltage with 50 kilohertz. Fluorescent lamp has percent flicker 28.4% according to [20].*

Some saying: "LED used DC voltage, so there is no flicker" correct? No

LED lamps are slightly different, as they use a DC (direct current) voltage source rather than AC (alternate current). However, the current vs. voltage function for LED has an exponential relationship as in figure 15, meaning small voltage ripples (from Va to Vb) will cause a huge, fast change in current (from Ia to Ib). The brightness of the LED is dependent on its power, which is defined by the expression P=IV (I=current, V=voltage). (IbxVb is much larger than IaxVa, so brightness of point b is much larger than brightness of point a) Because the current and power are proportional for voltage is almost the same, a instant change in current results in a instant change in power, which ultimately changes the brightness. Voltage ripples occur frequently, which then causes the brightness to fluctuate, therefore LED lights have flicker as well.

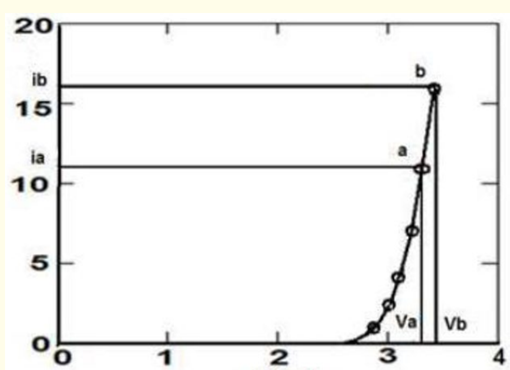


Figure 15: *Voltage and current relation of a LED lamp.*

Horizontal axis is the voltage across the LED (volt); vertical axis is the current through the LED (mA), as shown, a small voltage variation (from Va to Vb) causes a huge current variation from (ia to ib), and current is what controls the brightness of light.

LED lamp has percent flicker 54.7% according to [20]

The electronic displays of phones, notebooks, computers, tablets and TVs all use PWM (pulse width modulation) to dim brightness. High frequency pulses of voltage and current will result in light variation, which introduces yet again, the flicker problem.

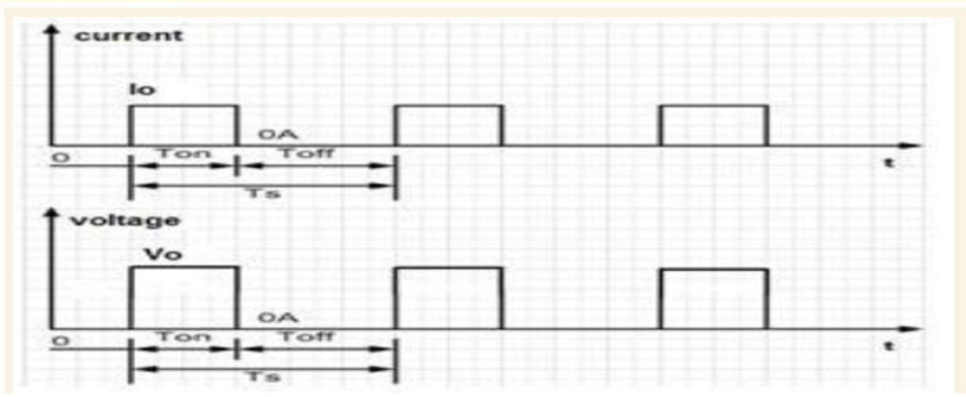


Figure 16: *Voltage and current of TV, computer, cell phone with PWM Average light output=IoxTon/Ts, maximum value A=Io, minimum value B=0; Percent Ficker=100%x(A-B)/(A+B)=100%x(Io-0)/(Io+0)=100%; average light output is IoxTon/Ts. Area1=(Io-IoxTon/Ts)xTon, Area 2=(IoxTon/Ts)xTon, Area 1+Area2=IoxTon Flicker Index=Area 1/(Area 1+Area2)=(Io-IoxTon/Ts)xTon/(IoxTon)=1-Ton/Ts Percent flicker.*

Summary of percent flicker of different lamps according to [20]:

Incandescent	Fluorescent	Commercial LED	Computer display	Bright Quantum LED
5.1%	28.4%	54.7%	100%	0%

Table

The flicker-free lamp on market has no flicker? -No.

Flicker

Modulation at 120 Hz cannot be seen, in most cases not even at 50 Hz (Seitz., *et al*. 2006). Fluorescent lamps including CFLs that use high-frequency (kHz) electronic ballasts are not seen, therefore, called "flicker free" [21].

Commercially advertised flicker-free lamps

Most lamps on the market that are labelled 'flicker-free' have invisible high frequency flicker (flicker frequency above 75Hz or even above 1kHz). Companies claim that the eyes do not feel the invisible flicker and therefore it does not cause eyestrain and myopia. However, technical test results prove otherwise.

If flicker is above 1250Hz, even 100% have no impact on vision, is it true?

Pupils will contract at bright light and will dilate at dim light. There is a specific pupil open area corresponding to the specific light brightness. For a sinusoidal flicker with peak magnitude 1, regular pupil open area corresponding to the effective value of the sinusoidal flicker is 0.707. area above 0.707 is defined as uncomfortable area. When the accumulated uncomfortable area is above a threshold, the pupil will shut once. For flicker, we need to consider the absolute value of sinusoidal waveform.

In the figure 17 below, the Blue area 1 is uncomfortable area for 60 Hz flicker, the Purple area 3 is uncomfortable area for 1260Hz. The pupil will shut every time when the accumulated uncomfortable area is above the threshold which results in eyestrain after many times of pupil shut.

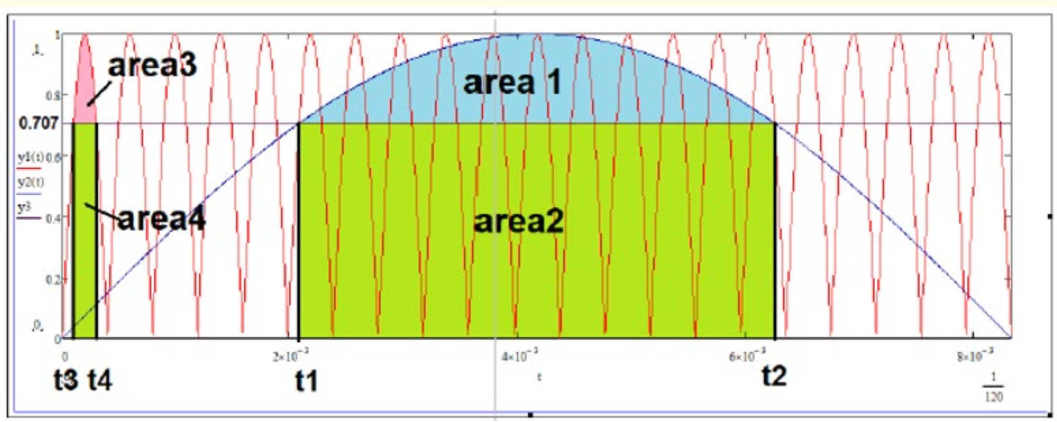


Figure 17: *60Hz flicker is blue curve and 1260 Hz flicker is red curve for 60 Hz flicker: area 1 is uncomfortable area and area 2 is comfortable area for 1260 Hz flicker: area 3 is uncomfortable area and area 4 is comfortable area Now let we calculate area 1 and area 3. From 0 to 1/120 seconds, there is only 1 of area 1 and 21x area 3.*

Firstly, let us calculate value of area 3, then total 21xarea 3

$$t3 := \frac{\left(\frac{\pi}{4}\right)}{2\cdot\pi\cdot 1260} \qquad t4 := \frac{\left(3\cdot\frac{\pi}{4}\right)}{2\cdot\pi\cdot 1260}$$

$$total\_3and4 := \int_{t3}^{t4} \left|\left|\sin[2\cdot\pi 1260(t)]\right|\right| dt \qquad area4 := \frac{\sqrt{2}}{2}\cdot(t4 - t3)$$

$$area3 := total\_3and4 - area4 \qquad area3 = 3.8335225193 \times 10^{-5}$$

$$21area3 = 8.0503972904 \times 10^{-4}$$

Figure B

Secondly, let us calculate value of area 1

$$\sin\left(3\cdot\frac{\pi}{4}\right) = 0.7071067812 \qquad \sin\left(\frac{\pi}{4}\right) = 0.7071067812$$

$$t1 := \frac{\left(\frac{\pi}{4}\right)}{2\cdot\pi\cdot60} \qquad t2 := \frac{\left(3\cdot\frac{\pi}{4}\right)}{2\cdot\pi\cdot60}$$

$$total\_1and2 := \left[\int_{t1}^{t2} \left|\sin[2\cdot\pi 60(t)]\right| dt\right] \qquad area2 := \frac{\sqrt{2}}{2}\cdot(t2 - t1)$$

$$area1 := total\_1and2 - area2 \qquad area1 = 8.0503972904 \times 10^{-4}$$

Figure c

Thirdly, we compare 21xarea 3 and area 1

By the above calculations, we see that Area1=21xArea3.

So, the flicker frequency's increase does not decrease the accumulated energy above the comfortable light limit. The flicker frequency's increase does not reduce the pupil shut times. Therefore, having higher frequency flicker does not decrease eyestrain nor protect against myopia. That calculation is not limited to 1260Hz, any high frequency flicker compare to 60Hz will not decrease eyestrain nor protect against myopia.

Besides the calculation result proof above, the following research result also proved high frequency flicker will not decrease eyestrain or myopia.

Research on eyes strain will cause myopia

Russian research: Physiological parameters of vision were studied in three professional groups (a total of 1204 subjects): microscope operators, subjects working with magnifying glasses, and computer users. General and specific features of visual system fatigue formation were identified. Because of complete (in microscope operators) or partial (in subjects working with magnifying glasses and display users) "deprivation" of accommodation, these subjects develop early presbyopia (at the age of 30-35 years). In microscope operators long strain of accommodation system leads to professional myopia, while display users develop pseudo myopia. The highest overstrain is observed after 4 years of work in microscope operators, after 5 years in magnifying glass users, and after 6 years in computer users [22].

Research on video display and computer for vision-cause myopia

Most of the video display and computer have high frequency flicker. Computer or smart phone's flicker firstly cause eyestrain, eyestrain induced myopia.

Japanese research: Subjects that worked at a computer terminal all day for 2 years, developed myopic change at a statistically significant level [23].

Russian Research: The total time of work with the display of more than 2 hours a day involved a decrease of the accommodation volume by 0.42-0.49 diopters and transitory myopia of 0.15-0.21 diopters, as well as increased self-appraisal of fatigue [24].

Screen use amongst the youth is becoming more of a problem in recent years, as the average age of myopia development is getting younger due to excessive screen use.

There was an example in Taiwan, there was a recent case in which a kindergarten-aged child had played on his mother's cellphone every day for several months. Due to the lengthy periods the boy spent staring closely at the screen, his ciliary muscles had lost the capability to adjust to things in the distance. He was later diagnosed with pseudo myopia. Pseudo myopia is a condition in which spasms of the ciliary muscles cause patients to develop symptoms similar to simple myopia. The healthcare system vice superintendent said more than 30 percent of children who have come to the clinic with eye problems had been playing on their mothers' cellphones. He added that if parents did not curb the tendency, the children could go develop high myopia [25].

Conclusion and Recommendations

Because of our constant dependency on artificial light sources, we need to take into consideration the effects of long-term exposure to flicker. Carelessly choosing light sources for regular use can permanently damage vision. Research should be done on the Percent Flicker and Flicker Index of commercial lamps before purchasing, as advertisements for "flicker free" does not guarantee the absence of invisible flicker, which is harmful to eye health. A true vision-protection lamp should have absolutely no flicker, meaning it has 0 Percent Flicker and 0 Flicker Index. Refer to www.uprlt.com.

What are other factors to affect vision?

Infrared (Wavelength > 800 nm): related to lens and retinal damage

Uppsala University in Sweden: Some scientific data suggests that near infrared radiation may cause cumulative damage in the ocular lens [26].

University of Texas at Austin, U.S. found the 1300-nm ocular damage data have yielded unusual characteristics where continuous wave retinal damage was observed in rabbit models [27].

Ultraviolet (Wavelength < 400 nm): related to cataract, macular degeneration, retinal damage and presbyopia

Fordham University in New York City, U.S. published paper 'Ultraviolet radiation as a risk of cataract, macular degeneration': Ultraviolet radiation is also a risk factor for damage to the retinas of children. The removal of these wavelengths from ocular exposure will greatly reduce the risk of early cataract and retinal damage [28].

College of Optometry, University of Houston, U.S. found UVR (ultra violet radiation) has most scientific support to affect the onset of presbyopia [29].

Strong blue light (peak > 90% all other light components peak): related to macular degeneration, photochemical damage.

University of Texas Southwestern medical center in Texas, U.S. research shows that excessive ocular blue-light exposure may contribute to age-related macular degeneration and other vision problems [30].

Karolinska Institute, St Erik's Eye Hospital, Stockholm, Sweden found Short-wavelength radiation (rhodopsin spectrum), and the blue light hazard (excitation peak 440 nm), have been shown to have a major impact on photoreceptor and RPE (retinal pigment epithelium) function, inducing photochemical damage and apoptotic cell death [31].

Monochromatic strong red: Myopia

Peking Union Medical College Hospital of China found guinea pigs raised in long-wavelength light (760nm) (red light) illumination developed a significant myopia [32].

Monochromatic strong green: Myopia

Eye and ENT Hospital, Fudan University of China showed guinea pigs in the green-light group had a somewhat myopic refractive status [33].

The spectrum test report for bright quantum LLC from UL showed there is no ultraviolet, infrared, no strong blue, red or green light. Refers to www.uprlt.com.

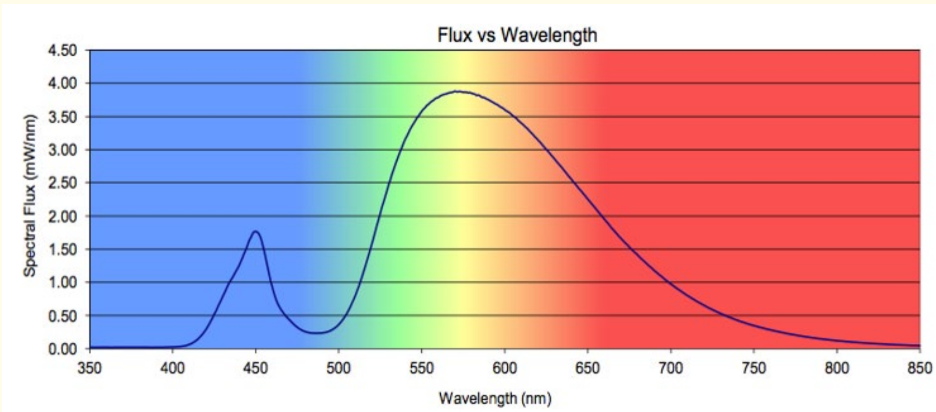


Figure D

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