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Review Article

Ophthalmology Section

Light Emitting Diode Lighting Flicker, its Impact on Health and the Need to Minimise it

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ABSTRACT

The existing technologies in Light Emitting Diode (LED) lighting sometimes cause flicker at frequencies that may have adverse health effects. Although, not always obvious to the human eye, it can make a difference in certain circumstances. Moreover, the flicker rate of many LED lights available in the market is much greater than conventional lights. This flicker has the potential to exert harmful effects on health. The various adverse effects of flicker include eye strain, fatigue, headache, migraine, blurred vision as well as photo epilepsy in sensitive individuals. In order to resolve the problem of high flicker, the foremost step is to develop a global standard for measuring flicker and then to have regulations for acceptable flicker limit. With the growing concern over LED flicker rate, many global lighting standards and specification communities have developed or are in the process of developing flicker measurement standards. In India, currently, there is no regulatory body to check the LED quality parameters with regard to flicker rate. Despite the fact that LED lighting products with high flicker rate carry a risk of flicker-induced health problems, a wide range of such products have penetrated the Indian market. The aim of this article was to summarise the information from the available literature about different types of flicker, methods to quantify flicker and potential health impact of flicker.

Keywords: Compact fluorescent lights, Eye strain, Flicker, Headache, Health impact, Light-emitting diodes

INTRODUCTION

There have lately been a lighting revolution with light-emitting diodes or LEDs replacing incandescent, fluorescent and Compact Fluorescent Lights (CFLs), both indoors and outdoors. LED is an energy-efficient, semiconductor, lighting technology. It emits light when an electric current is passed through it. It was invented by Nick Holonyak Jr. in 1962. As LEDs are energy efficient and have a long life, they are a popular source of light compared to conventional light sources such as incandescent bulbs and CFLs. They are used in home lighting, for television, laptop and phone screens, refrigerators as well as outdoors in street lights and parking garage lighting [1-4].

The LEDs have several advantages over the conventional lighting system [2,5]:

- Much more economical as they use about 25% to 80% less energy;
- More than 25 times longer lasting than conventional counterparts;
- Use energy more efficiently and unlike incandescent lamps which emit 90% of their energy as heat, LEDs emit very less heat;
- Do not contain mercury, so are eco-friendly;
- Emit very less carbon dioxide.

However, a major concern affecting the LED lighting industry is flicker or temporal light modulation (variation in light emission as a function of time which can cause changes in visual perception) [6,7]. Several investigations reveal that some LED products demonstrate high flicker rate, especially during dimming conditions [8].

WHAT IS FLICKER?

Wilkins AJ et al in their publication, LED lighting flicker and potential health concerns: IEEE standard PAR1789 update (2010), defined flicker as a rapid and repeated change in the brightness of light over time [9]. The Lighting Handbook (10th ed, 2011), published by the Illuminating Engineering Society of North America (IESNA) defines flicker as “a change in the luminous flux of a lamp or illuminant due to fluctuations in the voltage of the power supply” [6,10].

Types of Flicker

Flicker can be categorised into two types [6,7]:

- **Visible:** Visible flicker is consciously perceived and is considered unpleasant. It has biological and/or health-effects on humans.
- **Invisible:** Invisible flicker is not consciously perceived; nevertheless it may still have biological and/or health-effects on humans. Most humans are unable to perceive flicker in light above 60-90 Hz.

Importantly, flicker is not always harmful. Visible flicker may be used intentionally in discotheques or music concerts for stroboscopic effect (deceptive stopping or slowing of motion). Additionally, cyclists and runners use visible flicker as flashing rear light for safety [6]. However, in certain environments such as classrooms, offices, hospitals, industrial spaces and even homes where children/adults are exposed to light for several hours every day, it can cause health issues [6].

Some of the health-related adverse effects associated with flicker include [6,7]:

- Headaches, eye strain, blurred vision and migraines
- Aggravation of autism symptoms in children
- Photo epilepsy

Moreover, children, especially below three years of age, are more vulnerable to flicker-induced effects than adults [6]. Children have a higher sensitivity to blue light and the blue LEDs used in toys produce photochemical damage to the eye [7].

Flicker in certain industrial settings can cause performance issues by causing distraction. It may also lead to accidents because of its stroboscopic effect by changing the perception of rotating or moving machine parts [6].

Quantifying Flicker

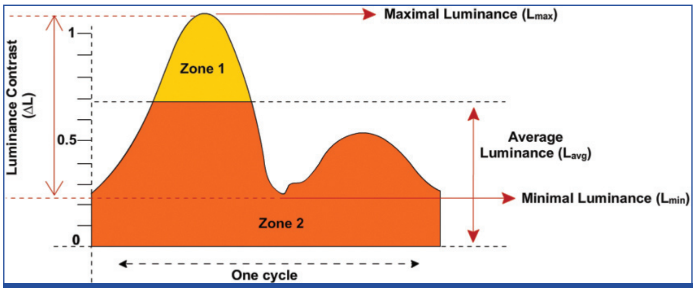
Flicker percentage and flicker index: These are measures to quantify flicker and determine LED lighting quality [6]. The Illuminating Engineering Society of North America (IESNA) in the 9th edition of the IESNA Lighting Handbook defined these two measures of flicker [11].

Flicker percentage is a measure of quantifying the amount of flicker at a given frequency [6]. It is a relative degree of the cyclic difference in output of a light source, i.e., percent modulation. Flicker percentage is therefore sometimes also known as modulation index [11]. A smaller flicker percentage implies lesser flicker [6].

Using [Table/Fig-1], the formula to compute flicker percentage is:

$$\% \text{ flicker}=100\times(L_{max}-L_{min}/L_{max}+L_{min})=100*(\Delta L/L_{max}+L_{min})$$

Flicker Index can be defined as a reliable relative measure of the cyclic variation in output of various sources at a given power frequency. It takes into consideration both the waveform of the light output and its amplitude. The flicker index ranges from 0 to 1, with 0 denoting steady light output. Higher flicker index values indicate higher possibility of perceptible flicker [11].



[Table/Fig-1]: Periodic Waveform Reference used for Calculation of Flicker Metrics [11].

Using [Table/Fig-1], the formula to compute flicker index requires the calculation of the areas of Zone 1 and Zone 2, and is defined as [11]:

$$\text{flicker index}=\text{Zone 1}+\text{Zone 2}$$

Globally, 26 lamps (including incandescent lights, LEDs and CFLs), were tested for flicker with a specialised device under real operating conditions (230 V 50 Hz pure sinusoidal stabilised voltage feeding). While all CFL and incandescent lights exhibited smooth flicker behaviour, LED lamps demonstrated varied flicker percentage, ranging from 0% to 100% [8]. This means that not all LED light sources out there in the market are of optimum quality. [Table/Fig-2] presents the flicker percentage and flicker index of common artificial light sources [11,12].

Technology	Percent flicker	Flicker index
Incandescent lamp	6.3	0.02
T12 linear with magnetic ballast	28.4	0.07
Spiral Compact Fluorescent Lamp (CFL)	7.7	0.02
Quad-tube CFL with magnetic ballast	37.0	0.11
Quad-tube CFL with electronic ballast	1.8	0.00
Metal halide lamp	52.0	0.16
High-pressure sodium lamp	95.0	0.30
Direct current LED	2.8	0.0037
LED with significant flicker	99.0	0.45

[Table/Fig-2]: Flicker metrics for common sources [11,12].

Unfortunately, there is currently no way to tell if a particular LED lamp would flicker or not, or at what rate it would flicker at the time of purchase [7]. Nevertheless, electrical societies and associations worldwide have now standards for LEDs that would limit flicker to acceptable levels. In India, these standards for LEDs are still missing, raising a question about the quality of these lights.

In order to find out the health impact of flicker on humans and how essential it is to have standards to limit flicker in LEDs, we performed a literature search on the effect of flicker.

The health effects of flicker can be either due to the immediate result of a few seconds' exposures, such as epileptic seizures. These are generally a result of visible flicker within the range of 3 to 70 Hz. Health-related issues such as uneasiness or discomfort, headaches and impaired visual performance are due to the less obvious result of long-term exposure. These occur as a result of invisible flicker present at frequencies above those at which flicker is perceptible [9,10].

IMPACT OF FLICKER

Impact of Visible Flicker

Neurological problems including photosensitive epilepsy in sensitive people can result even with very short exposures of visible modulation (3 to 70 Hz range). Estimated prevalence of this problem ranges from 1 per 100 000 to 1 per 4000. 1 in 4000 people aged 5 to 24 years of age. Onset most commonly occurs during adolescence and 75% of these individuals remain sensitive throughout life [8,10,13].

Impact of Invisible Flicker

Electroretinogram (ERG) that records the electrical potentials generated in the retina in response to the flicker indicate that invisible flicker is transmitted through the retina, and this flicker may lead to headaches and eye strain [4,14].

A number of studies in the past have shown that the modulation from cathode ray tube displays and fluorescent lamps affect the characteristics of eye movements across text [9]. A couple of studies have demonstrated that visual performance gets diminished while performing tasks that involve visual search because of flicker arising from fluorescent lights [9].

In a research work on 'Visual stimuli, light and lighting as common triggers of migraine and headache', approximately 25% to 50% of migraine sufferers mentioned flicker as the triggering factor for migraine. A survey conducted in 2010 and published in the Journal of Light and Visual Environment concluded that 22% of responding migraine sufferers cited flicker as a triggering factor for their migraine [10].

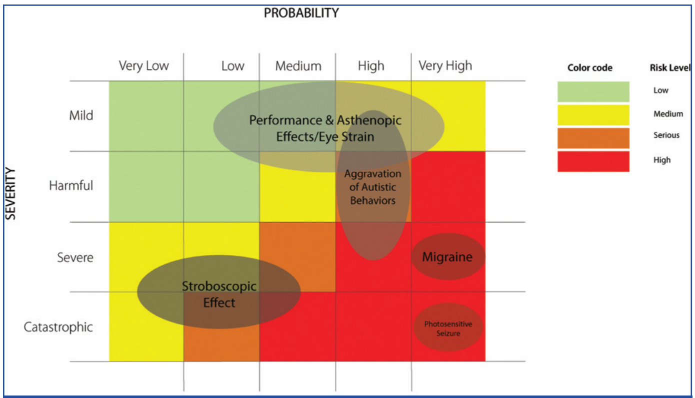
In 1989, Wilkins AJ, conducted a study to compare fluorescent lighting that flickered 100 times a second with lights that did not flicker. It was found that office workers working under the non-flickering lights were 50% less likely to experience headaches when compared to those working under the flickering lights [9,15]. Till date, no such study has been conducted for LED lights. It is, however, a well-established fact that the flickering from LED lights is even more distinct, hence there is a high probability that LEDs are more likely to cause headaches and other flicker-related health issues [15].

Despite the absence of any published case studies, some researchers claim that malaise, headaches and migraines get triggered at about 100 Hz flicker in some people who are very sensitive to it [7]. In addition, it has also been demonstrated that reading performance may be degraded in sensitive individuals and they may get distracted or annoyed due to flicker from electric light (including subtle changes in behaviour in susceptible individuals) [4].

The [Table/Fig-3] Summarises and categorises the types of flicker and the biological effects they cause.

In view of the growing concern over LED flicker, in 2008 the Institute of Electrical and Electronics Engineers (IEEE) P1789 committee was formed to research upon LED flicker issue and develop recommended practice [8,16]. The committee identified the following major adverse effects of flicker [10,12]:

- Photo epilepsy;
- Stroboscopic effect (in which objects in motion appear to slow down or stop) and related apparent stoppage or slowing of rotating machinery;
- Increased repetitive behaviour among people suffering from autism;
- Migraine or intense paroxysmal headache often associated with visual disturbances and nausea;
- Asthenopia (eyestrain with nonspecific symptoms), including fatigue, eyestrain, blurred vision, headache, and diminished sight-related task performance.



[Table/Fig-3]: Documented effects of flickering artificial lights [9].

The committee also identified anxiety, panic attack, and vertigo as potential effects of flicker but these have received little attention [10].

The [Table/Fig-4] demonstrates the risk matrix for the five identified adverse effects. This risk assessment involves five probability levels, four severity levels, and four risk levels (denoted by colour coding: red for high risk, orange for serious risk, yellow for medium risk and green for low risk). The definitions of probability levels and severity levels are given in [Table/Fig-5,6], respectively [10].

Source of flicker	Frequency range	Biological effect
Xenon gas discharge photo stimulator	3-60 Hz	Epileptiform Electroencephalogram (EEG) waveform abnormalities inpatients with photo sensitive epilepsy
Malfunctioning fluorescent lighting	Large 50 Hz component	Epileptiform EEG waveform abnormalities inpatients with photo sensitive epilepsy
Flashing televised cartoon	~10 Hz	Seizures in children with no prior diagnosis of epilepsy
Normally functioning fluorescent lighting (50 Hz ballast)	100 Hz (small 50 Hz component)	Eye strain and headache
Normally functioning fluorescent lighting (50 Hz ballast)	32% modulation	Reduced speed of visual search
Normally functioning fluorescent lighting (60 Hz ballast)	120 Hz	Reduced visual performance
Normally functioning fluorescent lighting (50 Hz ballast)	100 Hz	Rapid movement of eye overtext seems enlarged

[Table/Fig-4]: Risk matrix by hazard [10].

Probability	Potential injuries per million
Very low	0 to 0.01
Low	0.01 to 0.1
Medium	0.1 to 1
High	1 to 10
Very high	10 to 1000000

[Table/Fig-5]: Definition of probability levels [10].

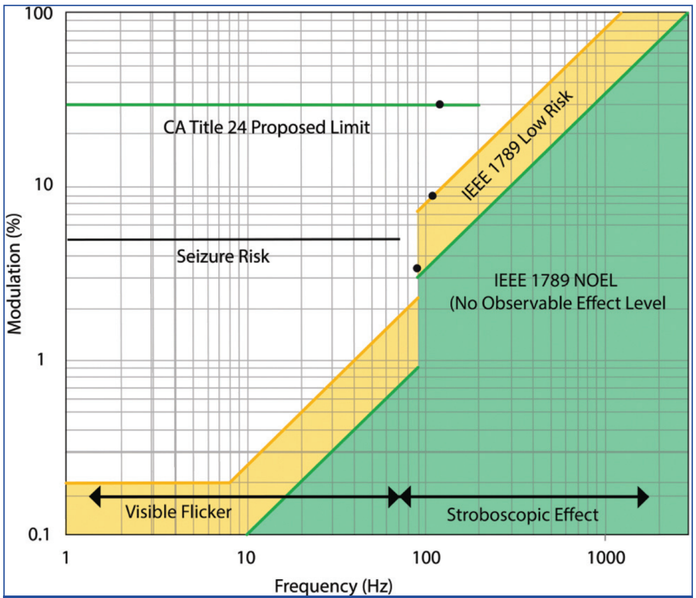
Factors that make Flicker Worse

Certain conditions worsen the adverse effects of flicker. These include: longer duration of exposure, greater area of retina receiving stimulation, central location in the visual field as it projects to a greater area of the visual cortex, greater brightness of the flash and higher contrast of the flash with the surrounding luminance [13].

It is important to note that the biological effects of flicker are a function of several factors. These include: flicker characteristics (mainly frequency and modulation depth) [Table/Fig-7], characteristics of the stimulus (luminance, spectrum, size, contrast), individual characteristics (individual differences in sensitivity, adaptation state of the eye), and others [10].

Severity	Impact on individual
Mild	• Mild discomfort or fatigue Malaise • Mildly decreased ability to concentrate
Harmful	• Sickness that does not require multiple workday absences • Measureable impaired visual performance • Vomiting • Significant discomfort • Significantly decreased ability to concentrate
Severe	• Hospitalisation • Sickness requiring multiple missed workdays • Substantial impaired visual performance including blurred vision • Severe photophobia Seizure
Catastrophic	• Death • Permanent injury/loss of life, limb, or function

[Table/Fig-6]: Definition of severity levels [10].



[Table/Fig-7]: Flicker modulation depth as a function of flicker frequency. Flicker modulation is given for noeffect level (green) and low risk level (yellow) [8].

DISCUSSION

Flicker factors for both visible and invisible flicker comprise of: modulation frequency, modulation amplitude, Direct Current (DC) component, and duty cycle [16]. The effects of flicker are dependent on the ambient light conditions, sensitivity of the individuals and the tasks being performed [17].

In order to achieve quality lighting from LED that is free from objectionable flicker, all 3 components of LED (controller or dimmer, LED driver and luminaire) must be compatible and the right LED driver must be selected [6].

LED flicker and dimming performance mainly depends upon the LED driver [12]. However, when selecting drivers for LEDs; the manufacturers have to take into account several factors such as cost, size, efficiency, and reliability [12]. A LED lamp is more likely to flicker if it is powered on Alternate Current (AC) [16]. Though capacitors in LED drivers can help control the AC ripples from the driver to LED, they too have certain limitations such as they are heat sensitive and large in size [12].

In addition, LED lamps are more likely to flicker if they have simple drivers (e.g., inadequate capacitors) and powered on DC, have Pulse Width Modulation (PWM) drivers or are dimmed with phase cut dimmers [16].

Measuring and reporting flicker is not a standard practice for commercially sold LEDs [17]. Even though flicker is a very important issue in terms of health, currently no light flicker regulation is implemented in various world-region regulations [8].

Unlike conventional lights, LED products demonstrate a wide variation across all flicker waveform attributes and exceeding the flicker range exhibited by conventional lights. While some LED lights exhibit negligible or no visible flicker, others show flicker percentage as high as 100% [17]. It is advisable to use low flicker LEDs especially in places where flicker can be problematic such as in offices, classrooms, laboratories, and industrial work and production areas. In addition, minimising flicker is more important where vulnerable populations spend considerable amount of time [17].

Some of the global organisations have documented flicker measurement metrics, however, there are still contradictions among them. A brief summary of these documents and their key aspects is given below [18]: IEEE 1789: "IEEE 1789: IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers" is a document that defines the challenges associated with LED flicker and potential health effects. It also delivers recommendations for diminishing the risk of adverse effects [18].

- **ENERGY STAR®:** The Environmental Protection Agency's (EPA's) ENERGY STAR program has addressed specific recommendations for flicker measurements and recommends using flicker percentage, flicker index and testing with five different dimmers, in case of dimmable LED products [18].
- **California Title 20 and Title 24:** The state of California has come up with a set of requirements. These requirements include the test method which needs measurement of the light output and dimmer for 2 seconds followed by running the data through a number of calculations for assessing flicker at multiple frequencies (up to 400 Hz). According to the set of requirements listed in title 24, high efficacy LED sources need to have 'low flicker operation', implying that the LED product at frequencies below 200 Hz will have flicker lower than 30%. 'Low flicker operation' is also required as per title 20 which covers LED lamps [18].

Even though flicker metrics have been developed by industry bodies they still have inadequacies. There are no well-defined thresholds to allow those metrics to be used to recognise harmful flicker for specific applications or populations [17]. The National Electrical Manufacturers Association (NEMA) emphasises that due to lack of adequate flicker assessment metrics, flicker standardisation is difficult. New flicker metrics and associated measurement methods for lighting which can be used as a standard worldwide are required [8].

Some new and improved flicker measurement procedures that have emerged are [19]:

1. **Pst LM (Short-term light modulation measuring procedure):** Developed by International Electrotechnical Commission (IEC), it measures visible flicker that occurs due to light modulation in the frequency range 0.3 Hz and 80 Hz. It takes about 1 minute to have a reliable assessment of low-frequency flicker phenomena with this method. The recommended limit for PstLM is ≤1 [19].
2. **SVM measuring method:** SVM stands for stroboscopic visibility and this method measures strobe effect that can occur together with moving objects and a light modulation in the frequency range 80 Hz to 2,000 Hz. A signal duration of at least 1 second is needed for quantifying the value of the SVM. The thresholds for SVM are yet to be set [19].

One of the simple and effective methods suggested by Kitsinelis S et al., for consumers to detect light flicker involves the use of a mobile phone camera. By simply targeting the LED lamp and looking it on the mobile screen, one can determine the high or low flicker rate. If striations or dark fringes appear around the lamp then flicker is present [20]. When fringes are visible in camera then flicker rate is more than 20%. When striped images of LED light appear on the screen, it indicates high flicker rate whereas when stripes tend to fade, it indicates low flicker rate. If no fringes appear on the mobile screen then it implies that the lamp has very little or no flicker [8].

LIMITATION

Lack of prior research studies on the topic; overall, there was a lack of available data on the quantification methods of flicker and impact of flicker on human health. While there is available literature on some methods of flicker quantification, there are no studies conducted to suggest which method is better among the currently available methods. Also, there is a lack of available data on the impact of flicker on human health in different settings. Thus, to fill these gaps, more studies need to be performed in order to fully explore these areas.

No study on impact of LED flicker; while reviewing literature, it was found that currently there is no research study conducted specifically to ascertain the health impact of LED flicker. All studies cited in the article for describing the impact of flicker have either been done on conventional or other light sources. Keeping in view growing concern about LED flicker, it is important that future studies should be conducted on the impact of LED flicker on healthy subjects comprising all age groups as well as on vulnerable subjects.

CONCLUSION

Due to the multitude of advantages, such as less power consumption, better efficacy and longer life, LED lights are rapidly taking over conventional lights with their increased commercial availability. However, in recent years emerging research has shown that some LEDs in the market may demonstrate high flicker rate that can have harmful implications. This has led to concerns regarding health impact of LED flicker and ensuing debates about their safety.

Previous researches have already shown that flicker is responsible for a number of health issues including: eyestrain, fatigue, headache, migraine, triggering photo epilepsy, and autism episodes in vulnerable individuals.

It is seen that with LED sources the severity and range of flicker is relatively very high when compared to conventional lights. This has led to the development of flicker quantifying measures by global lighting standards and specification communities.

These flicker metrics, though helpful for LED manufacturers, are just recommendations and not the global standard methods. Unfortunately, in India, the situation is worse as a huge number of brands have penetrated the market and are selling LED lights with no regulatory body to check the quality parameters in terms of flicker. Thus, keeping in view the current situation, there is a dire need for a reliable and globally standard flicker metric that can help the lighting industry both nationally and globally.

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