Fact sheet screens and projectors

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The screens of multimedia devices and projectors produce coloured images that are composed of many different colours. The electronic part of the devices mixes together blue, green and red light in different proportions to produce the various colours. To obtain these three primary colours, artificially-produced white light is passed through blue, red and green colour filters. Modern screens produce the three colours directly using blue, green and red LEDs, while projectors also user lasers.

Effects on health

Excessive blue light can cause damage to the retina. Blue light, which affects people in the evening, can influence sleep and wake cycles (circadian rhythm), hormones and other physiological processes. Artificial light that is not constant and flickers can have a disruptive effect on humans. A study conducted on behalf of the FOPH measured the radiation from the screens of various devices and projectors to be able to assess these effects.

Blue light hazard to the retina:

To ensure blue light from devices does not damage the eyes, it must comply with the exposure limit for blue light hazard. This limit depends both on the intensity of the blue light and the time during which the retina is exposed to it. A distinction is drawn between the following risk groups:

- Devices in the 'exempt group' comply with the exposure limit even when used for several hours, and are safe for everyone, including children.
- Devices in risk groups 1 and 2 comply with the exposure limit if the eye is exposed for short periods of time and do not pose a hazard during these exposure times.
- Devices in risk group 3 damage the retina even after momentary exposure times of tenths of a second.

The study conducted on behalf of the FOPH showed that all devices with screens that were examined belong to the exempt group. The tested projectors belong to risk groups 1 and 2 if a person looks directly into the light beam. The study did not identify any devices belonging to risk group 3.

The exposure limit prevents health hazards that may occur in the space of seconds to hours. It is not possible to assess whether chronic exposure over several years to visible radiation below the blue light exposure limit can cause long-term health risks.

Influence of blue light in the evenings on the circadian rhythm and hormones:

There is sufficient evidence to suggest that cold white bluish light from screens, which affects people in the evening, can influence their circadian rhythms. This effect particularly occurs in people who spend little or no time in daylight during the day. The disrupted sleep/wake cycles impact sleep, certain hormones and other physiological functions. Research is currently being conducted to understand whether these effects cause health hazards over long periods. The FOPH study shows that the blue light radiation emitted by screens can be reduced using electronic filters or by decreasing the display brightness.

Flicker

The FOPH study shows that screens may flicker if they are not on the maximum brightness setting. Regarding potential effects on health, there are indications that in susceptible individuals, flickering light can cause headaches, migraines and in very rare cases epilepsy.

The following tips help ensure safe use of devices with screens, such as computers, tablets, smartphones and televisions

The blue light from computer, tablet, smartphone and television screens does not present a risk for the eyes, so no protective measures are needed against blue light hazard.

The blue light emitted by the screens of computers, tablets, smartphones and televisions can affect circadian rhythms, hormones and other physiological processes.

- You should therefore reduce the brightness of your screens in the evening so that you do not have to strain your eyes. You can adjust the brightness via the operating system.
- You can also reduce the proportion of blue light emitted by screens in the evening. To do so, you can use the device's electronic blue light filter. The blue part of the light that enters the eye can be reduced with appropriate blue light filter films or blue light filter glasses.

Give your eyes a break now and again when using screens, ideally by looking into the distance or spending some time outside. This will also help support your body's circadian rhythm.

If you are sensitive to flickering light,

- ideally you should use devices with screens that can be dimmed without flicker using DC or constant current dimming, or devices that do not produce glare at full brightness and that you do not need to dim;
- particularly when using very large screens, you should take care to ensure sufficient distance between yourself and the screen so that you can at least see the edges of the screen and some of your surroundings.

Projectors must be handled by a professional to prevent health risks:

- Never look directly at the light beam from a projector. Set up projectors in such a way that people (especially children) cannot stare into the beam. The light reflected off the projector screen is not hazardous.
- Take note of the safety notice in the instruction manual.

Further information

1 Structure and radiation characteristics

The screens of smartphones, tablets, laptops, computers and televisions, as well as projectors, work with various technologies that produce visible radiation in different ways. They are described below.

1.1 Screens with backlighting

The coloured radiation in today's screen technologies is based on light in the primary colours red, green and blue. These three primary colours are produced from white light from the backlighting, which is built into the screen's interior. The light is passed through red, green or blue coloured filters. Each group of three coloured filters represents one of the many pixels on a screen. Depending on the proportions of the individual primary colours, these pixels light up in the desired mixed colours. If the three primary colours of a pixel are set to the highest intensity, you get a pixel emitting white light, while if they are set to the lowest intensity, the pixel is black.

The white light in backlighting is produced using various technologies. Older technologies work with cold cathode fluorescent lamps (CCFL). They produce ultraviolet radiation, which is converted by the fluorescent coatings on the inside surface of the tube into different visible coloured radiation components that when mixed together are white (Figure 1).

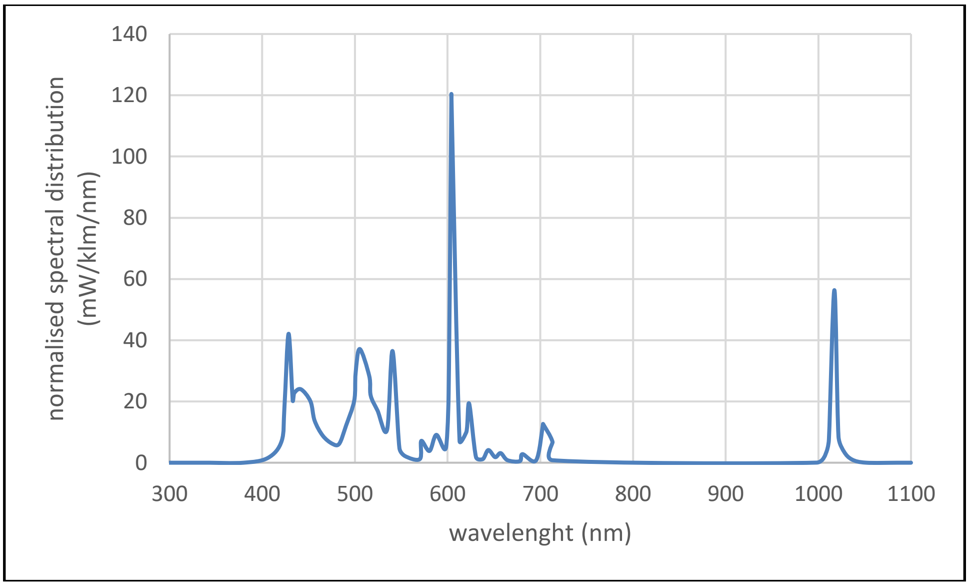

Figure 1 Spectrum of a computer screen with CCFL backlighting

Current technologies use inorganic light-emitting diodes (LED). These LEDs produce blue light, some of which is converted into yellow-red light via fluorescent coatings on the inside surface of the diode, which together with the blue part yield a mixed white light (Figure 2).

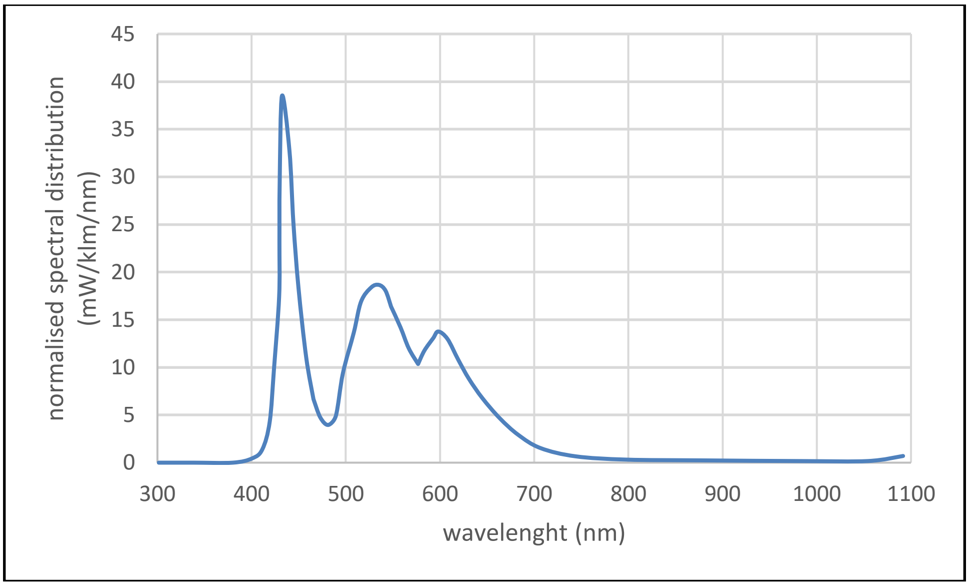

Figure 2 Spectrum of a screen with LED backlighting

Screens for graphics that need to represent a broad colour range sometimes work with a combination of one blue and one green LED per pixel, which both produce red light via an additional phosphor coating.

The backlighting of screens can also be built with white organic light-emitting diodes (WOLED or WRGB), which consist of red, green and blue organic LEDs stacked on top of each other, which result in a mixed white light.

In screens with LED backlighting, the backlighting has a blue part that is more or less pronounced depending on the set colour temperature.

1.2 Screens without backlighting

Screens without backlighting are used in tablets, smartphones, computers and televisions that work with organic light-emitting diodes (OLED). Each pixel is formed from three light-emitting diodes in red, green and blue. The desired colour of the pixel is determined by the intensity of each of the light-emitting diodes. When all three light-emitting diodes in a pixel are on maximum brightness, the result is white light. This technology is also known as RGB-OLED (Figure 3).

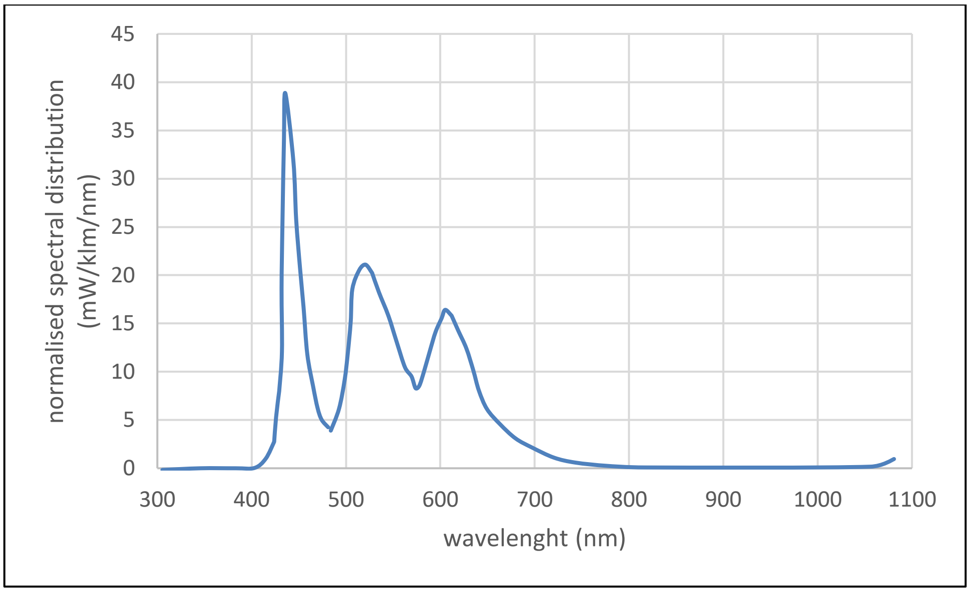

Figure 3 Spectrum of a screen with RGB-OLED technology (without backlighting)

1.3 Adjusting screen brightness

Depending on the design and operating mode, a device's power supply produces current that fluctuates more or less strongly. As a result, the intensity of the light emitted by the device fluctuates, which gives rise to what is known as flicker.

1.4 Projectors

1.4.1 LCD projectors

LCD (Liquid Crystal Display) projectors predominantly use metal halide lamps and less commonly LEDs or lasers. These light sources produce white light using various principles that is split into the primary colours blue, green and red by dichroic mirrors. These three colours then illuminate three identical LCD components. The LCDs consist of a configuration of many pixels that can allow different amounts of light to pass through as required. Three pixels arranged identically in the three LCD components together form a pixel group, which produces light beams in blue, green and red. These three light beams hit a prism which mixes them and produces a beam with the desired colour tone. The mixed beam is then projected onto the screen using a projection lens, where it produces a pixel. As a result of this principle, the beam from LCD projectors may contain a significant proportion of blue light.

1.4.2 DLP projectors

DLP projectors comprise a light source that produces white light. The light illuminates what is known as a colour wheel that rotates. The colour wheel consists of several transparent coloured segments. When it rotates, it produces blue, green and red light sequentially. This light then hits a DLP chip. The chip is lit either blue, green or red at a given time. It is made up of thousands of microscopic mirrors which are electronically controlled to tilt towards the light beam or away from it. Depending on their position, the mirrors may or may not be able to reflect light.

Each of these microscopic mirrors represents a colour point or pixel in the projected image. The DLP chip produces the desired mixed colours by projecting the primary colours sequentially onto the screen in the desired quantities using a projection lens. Because these mirrors can tilt towards the light beam up to several thousand times per second, the human eye perceives a distinct colour even though it actually consists of individual primary colours projected onto the screen sequentially. As a result of this principle, the beam from DLP projectors may contain a significant proportion of blue light.

1.4.3 LED projectors

LED projectors work according to the LCD/DLP projector principle. Blue, red, and green LEDs are used as light sources. The light from these LEDs is either mixed together to give white light or directed onto the LCD or DLP chips.

1.4.4 Laser projectors

Laser projectors for home use work according to the LCD/DLP projector principle. Instead of a white light source, blue, red and green lasers are used. The beam from these lasers is either mixed to become a white light or directed straight onto the LCD or DLP chips. For safety reasons, devices for home use do not contain powerful individual lasers, but instead configurations with several less powerful lasers.

2 Health effects of screens

2.1 Visible light

2.1.1 Effects on health

The degree with which light enters the retina unhindered depends on a person's age. In very bright light, the retina, other tissues and the eye's photoreceptor cells are exposed to excessive illumination. This results in thermal and photochemical processes that can cause severe and irreversible damage to the eye, and can lead to a partial loss of sight or even blindness. Excessive blue light or blue light hazard presents a risk to the general population. Photochemical damage can also result from the reaction of blue light with substances stored in the eye, such as lipofuscin, which accumulates with age (Behar-Cohen et al. 2011).

2.1.2 Exposure limits and standards for blue light hazard

To prevent the acute risks of visible and infrared radiation, the International Commission for Non-Ionizing Radiation Protection has recommended exposure limits (ICNIRP 2013)that also apply to blue light hazard. The exposure limit for blue light hazard restricts the blue light that enters the retina and is intended to prevent acute health hazards. This exposure limit is based on the effective dose of radiation resulting in a 50% probability of retinal injury or damage. This exposure limit is characterised as a dose, in other words the radiance multiplied by the duration of exposure. This means that for very long periods of exposure, the viewed radiance must be very small, or for very short exposure periods, the radiation can be high. The blue light hazard exposure limit distinguishes two cases. 1) Normal eyes with lenses, and 2) eyes that are sensitive to blue light, such as those of children or people who either have no or very clear synthetic eye lenses as a result of a cataract operation.

The European Lamp Standard EN 62471 which is also used to assess light sources such as screens and projectors, translates the blue light hazard exposure limits into various risk groups (Table 1). The risk groups differ in the exposure period during which the retina can be exposed to a light source before the exposure limit is reached. The standard draws a distinction between light sources that can be used for unlimited periods without posing a hazard due to their low radiation, and those that can only be used safely for limited or very short periods due to their powerful radiation. The following risk groups are defined:

Lamp risk group	Eye exposure time during which the blue light hazard exposure limit is reached	Labelling of lamp with risk group	Cautions/warnings
Exempt group	More than 10,000 seconds	Not required	Not required
Risk group 1	Between 100 and 10,000 seconds	Not required	Not required
Risk group 2	Between 0.25 and 100 seconds	Required	Cautions required
Risk group 3	Less than 0.25 seconds	Required	Warnings required

Table 1 Risk groups

The risk groups give a relatively broad indication of blue light hazard as the permissible exposure times within a risk group cover a large range. A more meaningful way of evaluating a light source is to look at how long the retina can be exposed to the radiation before the exposure limit is reached.

Light sources belonging to risk groups 2 and 3 should be labelled with their risk group and bear a caution or warning label on the packaging or include a package insert. For light sources that do not belong to the exempt group, the user information must clearly indicate that the product is not classified in the exempt group (IEC TR 62471-2).

2.1.3 Long-term effects

The exposure limit mainly covers the health risks that have been well researched and which occur following exposure times of less than one second to several hours. It is impossible to assess whether the exposure limits for visible light can also prevent health effects such as macular degeneration (the area of the retina responsible for focusing central vision) in the case of chronic life-long blue light exposure, as not enough scientific research has been conducted in this area. (Shang et al. 2014; Moon et al. 2017)

2.1.4 Blue light hazard of different product groups

A study conducted by METAS on behalf of the FOPH studies the blue light hazard of smartphones, tablets, e-readers, screens, laptops, televisions and projectors.

Smartphones, Tablets, e-readers, Computer screens, Laptops, Televisions

The results show that the screens of smartphones, tablets, e-readers, computers, laptops and televisions belong to the exempt group (Table 2). The blue light from these screens is not hazardous to people, even if they use such screens for longer periods.

Light sources	Distances	Maximum exposure time	Risk group
Smartphones	20 cm; 30 cm	> 10,000 s	Exempt group
Tablets, e-readers	20 cm; 30 cm	> 10,000 s	Exempt group
Computer screens	30 cm; 60 cm	> 10,000 s	Exempt group
Laptops	30 cm; 60 cm	> 10,000 s	Exempt group
Televisions	30 cm; 60 cm	> 10,000 s	Exempt group

Table 2 Maximum exposure times and risk groups of smartphones, tablets, e-readers, screens, laptops and televisions

Projectors

The results show that projectors may belong to risk group 2 at distances of up to three metres, depending on the model (Table 3). This means that even a brief glimpse into the beam of a projector can damage the eyes. This presents a hazard to both normal and sensitive eyes. Projectors should therefore be used in a way that ensures people cannot stare straight into the beam. This can be done by mounting them on the wall at a safe height or on the ceiling. For projectors that are temporarily set up on tables, users must make sure that neither they nor the audience can intentionally or inadvertently stare directly into the beam.

Distances	Range of values for 3 different models of projectors			
	Maximum exposure times		Risk group	
	Normal eyes	Sensitive eyes	Normal eyes	Sensitive eyes
30 cm	2 to 17 s	2 to 16 s	RG2	RG2
1 m	10 to 52 s	9 to 51 s	RG2	RG2
3 m	54 to 10,000 s	52 to > 10,000 s	RG2, exempt group	RG2, RG1, exempt group
Reflected radiation of an image projected onto a screen at a distance of 3m	> 10,000 s	> 10,000 s	Exempt group	Exempt group

Table 3 Maximum exposure times and risk groups of projectors for normal and sensitive eyes. Measurements for three projectors

2.1.5 Health assessment

According to the current science, the blue light from screens does not pose a risk to eye health. This also applies to children and people with no or very clear lenses. However, when using projectors, care must be taken not to look straight into the beam at close range. The long-term effects of the blue light from all listed products cannot be assessed.

2.2 Biological rhythms

2.2.1 Basic information on the circadian effects of blue light on physiological functions

Many of the human body's physiological processes work according to a predetermined temporal pattern. These include hormonal rhythms such as melatonin and cortisol, the immune system, body temperature, the sleep/wake cycle, mental performance and many other processes. (CIE 2009). They are subject to the so-called 24-hour circadian rhythms, which are mainly controlled by the 'internal clock' located in the brain. Because this brain function does not have an exact 24-hour rhythm, it has to be adjusted daily. This mainly occurs by means of the blue light in daylight, which enters the retina as soon as it gets light in the morning. This light is absorbed by the light-sensitive nerve cells in the retina and by the photoreceptor cells, and is converted into nerve impulses that are transmitted to the brain's internal clock.

Blue light, which is especially pronounced in daylight, has a stimulating effect on the body in the morning and throughout the day. However, in the evening or at night, the stimulating effect of blue light can have undesirable consequences as despite it being night time, it tells the body that it is day time. This disrupts the processes that prepare the body for sleep or that take place during sleep. This boosts wakefulness and alertness, for example, and suppresses melatonin (the hormone of darkness), which can cause people to have difficulty falling asleep. Such effects can occur even at low irradiance levels. Besides these sorts of acute effects, scientific findings increasingly show that as a consequence of the disturbed physiological rhythms, shift work may even cause severe long-term health effects, such as cancer and being overweight. (IARC 2010)

2.2.2 Exposure limits and standards

Currently there are no exposure limits for the circadian effects of visible light. The standard DIN SPEC 5031-100 defines a melanopic action factor to characterise the circadian properties of light sources. The melanopic action factor of a light source describes the ratio between the melanopic response (of the cells in the eye that help control circadian rhythms) to the visual response. (Bellia et al. 2014; Bellia und Seraceni 2014) A melanopic action factor of 1 corresponds roughly to daylight outdoors on a cloudy day. Light sources with melanopic action factors of 1 therefore have similar stimulating properties on the body to daylight, whereas effect factors of below 1 stimulate the body less than daylight. The melanopic action factor allows comparison of different light sources, but does not give any indication of the actual circadian effect of the light from a light source.

2.2.3 Melanopic action factors of devices with screens and projectors

The study conducted by METAS on behalf of the FOPH determined the melanopic action factors of products with screens. Figure 4 shows the results for laptops, computer screens and televisions in four different operating modes: standard brightness; standard brightness warm light (with night mode); minimum brightness; minimum brightness warm light (with night mode). Figure 5 shows the mean melanopic action factors of smartphones, e-readers and tablets in the operating modes standard brightness and minimum brightness. The results show that particularly in laptops and to a lesser extent in computer screens and televisions, the night mode reduces the melanopic action factor of the light. However, at >0.6-0.95 the melanopic action factors are still quite high compared with ambient lighting with warm white energy-saving lamps or LEDs (approx. 0.4).

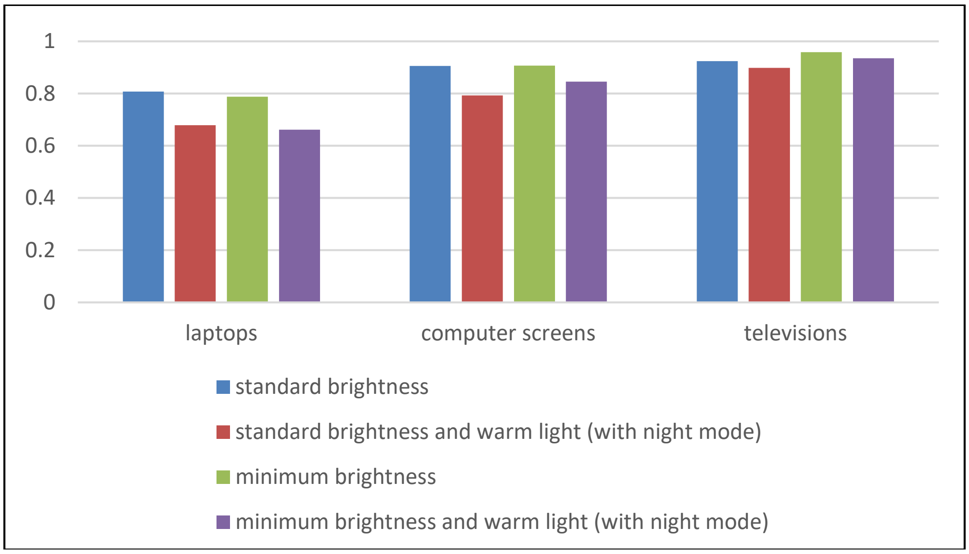

Figure 4 Circadian effects of devices with screens: Mean melanopic action factors of laptops, computer screens and televisions in operating modes standard brightness, standard brightness and warm light (with night mode), minimum brightness, minimum brightness and warm light (with night mode).

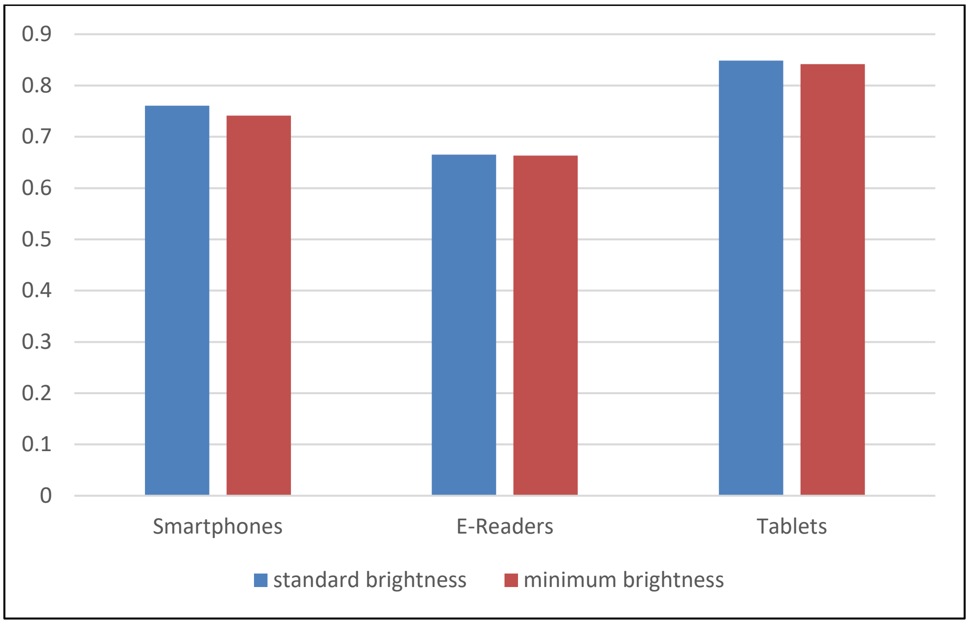

Figure 5 Circadian effects of devices with screens: Mean melanopic action factors of smartphones, e-readers and tablets in the operating modes standard brightness and minimum brightness

2.2.4 Health assessment

Depending on the intensity, blue light from screens can influence the body's circadian rhythms. One way of measuring this is the screen's colour temperature, which can be configured via the operating system of many devices. Colour temperatures of 3,000 kelvins produce light with similar properties to ambient light bulbs or warm white energy-saving or LED lamps. This colour temperature setting is suitable when using devices with screens in the evening. Devices whose screens are set on cold white or bluish with high colour temperatures of 4,000 – 8,000 kelvins are suitable for use in the daytime.

2.3 Flicker

In screens and projectors, the brightness of the emitted light can fluctuate to a greater or lesser extent depending on the product. These fluctuations in brightness are known as flicker if they are perceived by humans as unsteady or fluttering light. The temporal fluctuations in brightness or flicker depend on the technology and quality of the backlighting power supply, which supply these devices with energy. Flicker particularly occurs with pulse-width modulation power supplies (PWM power supplies). When dimmed, they periodically reduce the power or even periodically switch it off. As unlike fluorescent tubes, LEDs do not have photoluminescence properties, the fluctuations in current are directly transferred to the emitted light. If the frequency of the PWM power supply is too low, flicker may occur. Screens that work with DC (direct current) dimming or constant power dimming produce a continuous current that is not or only slightly pulsed, and therefore has no or only minimal flicker.

2.3.1 Effects of flicker on humans

In most cases, the human eye can recognise flicker up to a frequency of 30 to 60 hertz. Flicker with frequencies of 100 hertz or more can no longer be consciously recognised by the human eye. However, the retina can detect flicker of up to 500 hertz without the person even being aware of it.

There has been very little scientific research into the health effects of flicker, and what is known mainly comes from studies on fluorescent tubes with conventional ballast units. Flicker can cause both immediate and long-term health effects. The immediate effects particularly affect people who suffer from photosensitive epilepsy. They are at risk if the flicker frequency is between 3 and 70 hertz. Longer-lasting exposure to flicker can lead to headaches, migraines, sore eyes, impaired vision, difficulty concentrating and reduced productivity (Wilkins et al. 2010; Karanovic et al. 2011; Shepherd 2010). Flicker from large light sources, such as large screens and widescreen televisions at close range can be perceived by humans better than flicker from small point sources. As a result of the short distances, screens irradiate the peripheral retina, which is more sensitive to flicker. Flicker is also more visible from light sources with high luminance (Becker 2019, Emoto 2012).

2.3.2 Exposure limits

There are currently no binding exposure limits for flicker. The flicker characteristics of a light source are given as 'per cent flicker' or as a flicker index. (Poplawski und Miller 2013) A percentage of 0 means that a light source does not have any flicker and radiates continuously, while a percentage of 100 means that the intensity of the light switches periodically between maximum brightness and darkness.

2.3.3 Intensity of flicker by device category

The study conducted by METAS on behalf of the FOPH shows that the screens of smartphones, e-readers, tablets, laptops and computers feature no or very little flicker on maximum brightness. On minimum brightness the flicker characteristics vary from one model to the next. Certain models do not produce any flicker, while others have maximum flicker. The televisions measured featured pronounced flicker, both on minimum and maximum brightness. Projectors can also give strong flicker on maximum brightness (table 4).

Lamp of device types	Brightness	% flicker: Device with lowest value	% flicker: Device with highest value
Smartphone	maximum brightness	0	7
Smartphone	minimum brightness	0	96
e-reader	maximum brightness	0	0
e-reader	minimum brightness	0	1
Tablet	maximum brightness	0	7
Tablet	minimum brightness	0	95
Laptop	maximum brightness	0	0
Laptop	minimum brightness	0	100
Computer screen	maximum brightness	0	15

Computer screen	minimum brightness	0	100
Television	maximum brightness	83	99
Television	minimum brightness	97	100
Projector	maximum brightness	7	100
Projector	minimum brightness	5	100

Table 4 Flicker characteristics of screens and projectors

2.3.4 Health assessment

The flicker characteristics of a screen can be determined using a smartphone camera or digital camera focussed on the screen. If the camera image has streaks, the photographed screen has flicker. It is not possible to conclusively assess at present whether LED flicker presents a health risk. (SCENIHR 2018). As a precautionary measure it is therefore advisable

- to use flicker-free screens where possible. These products are marketed under the term DC dimming;
- not to dim screens if they are being used by people who suffer from epilepsy, migraines or headaches.

3 Legal regulation and standards

As low-voltage electric equipment, screens and projectors must meet the requirements of the Ordinance on Low-Voltage Electrical Equipment (LVEO, SR 734.26). Low-voltage electrical equipment may only be placed on the market if it does not endanger persons or property, and if it meets the basic health and safety requirements set out in the EU Directive 2014/35/EU. The basic requirements are specified in European standards. The permitted optical radiation is set out in European standard EN 62471:2008 and is based on the International Commission on Non-Ionizing Radiation Protection's Guidelines on limits of exposure to incoherent visible and infrared radiation.(ICNIRP 2013). Manufacturers are responsible for ensuring their devices meet these compliance criteria.

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