Review

Blue Light and Digital Screens Revisited: A New Look at Blue Light from the Vision Quality, Circadian Rhythm and Cognitive Functions Perspective

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ABSTRACT

Research conducted over the years has established that artificial light at night (ALAN), particularly short wavelengths in the blue region (~400–500 nm), can disrupt the circadian rhythm, cause sleep disturbances, and lead to metabolic dysregulation. With the increasing number of people spending considerable amounts of time at home or work staring at digital screens such as smartphones, tablets, and laptops, the negative impacts of blue light are becoming more apparent. While blue wavelengths during the day can enhance attention and reaction times, they are disruptive at night and are associated with a wide range of health problems such as poor sleep quality, mental health problems, and increased risk of some cancers. The growing global concern over the detrimental effects of ALAN on human health is supported by epidemiological and experimental studies, which suggest that exposure to ALAN is associated with disorders like type 2 diabetes, obesity, and increased risk of breast and prostate cancer. Moreover, several studies have reported a connection between ALAN, night-shift work, reduced cognitive performance, and a higher likelihood of human errors. The purpose of this paper is to review the biological impacts of blue light exposure on human cognitive functions and vision quality. Additionally, studies indicating a potential link between exposure to blue light from digital screens and increased risk of breast cancer are also reviewed. However, more research is needed to fully comprehend the relationship between blue light exposure and adverse health effects, such as the risk of breast cancer.

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Keywords

Light; Smartphone; Circadian Clocks; Blue Light; Cognitive Functions; Vision Quality

Introduction

The circadian rhythm as a natural, internal process regulates the sleep-wake cycles; although circadian rhythms are endogenous, they are affected by external factors including light, temperature, and redox cycles [1]. All creatures such as humans have two timing systems as follows: **1)** it is in suprachiasmatic nuclei (SCN) that serve as "biological clocks" and regulate different daily rhythms such as sleep-wake cycle and reset daily with sunrise. Given this consideration, destruction of the SCN can lead to the complete impairment of a regular sleep-wake rhythm [2-5]. Thus, regular changes of light cause the adjustment of key body functions, including hormones secretion (such as melatonin and cortisol), awareness, body temperature, heart rate, and cognitive and behaviour function to be affected to be regulated due to sleep-awake adjustment [6-13]. As shown in Figure 1, the blue light emitted from digital screens can increase the risk of some cancers through affecting the melatonin level and biological rhythms. Given this consideration, digital screens as well as other sources of ALAN can affect the master clock located in the SCN of the hypothalamus and decrease the nocturnal melatonin synthesis in the pineal gland that causes disruption of circadian rhythms [14].

Neurological studies showed that there was a correlation between non-visual cognitive functions of the brain and subcortical areas such as the pulvinars, hypothalamus, and brainstem [15, 16]. **2)** It is in striate-cortical loops and leads to passing time like passing minutes and seconds [17]. Does light have effects on the brain of just sighted people or includes the same effects for blind people as well? Actually, there is still light effects, including the suppression of melatonin secretion and sleep disorders even without any ocular cells making images. There are two kinds of cells in the retina, including imaging and non-imaging cells which account for human vision and adjustment of key body functions, respectively. In addition to the image effects, non-image effects should be considered to evaluate the role of cones, rods, and *intrinsically photosensitive retinal ganglion cells* (ipRGCs) [18]. The cell called melanopsin in the retina [19, 20] is responsible for the adjustment of sleep rhythm and suppression of melatonin [3, 21], placed in retinal ganglion cells with high sensitivity to short-wavelength lights, especially blue light [18]. The melanopsin and their information are sent by the retinohypothalamic tract to the SCN. Due to blue-light stimulation, the message is sent to suprakiasma to affect the pineal gland and then regulate melatonin secretion [22, 23]. Melatonin is released by the pineal gland and has different levels during the

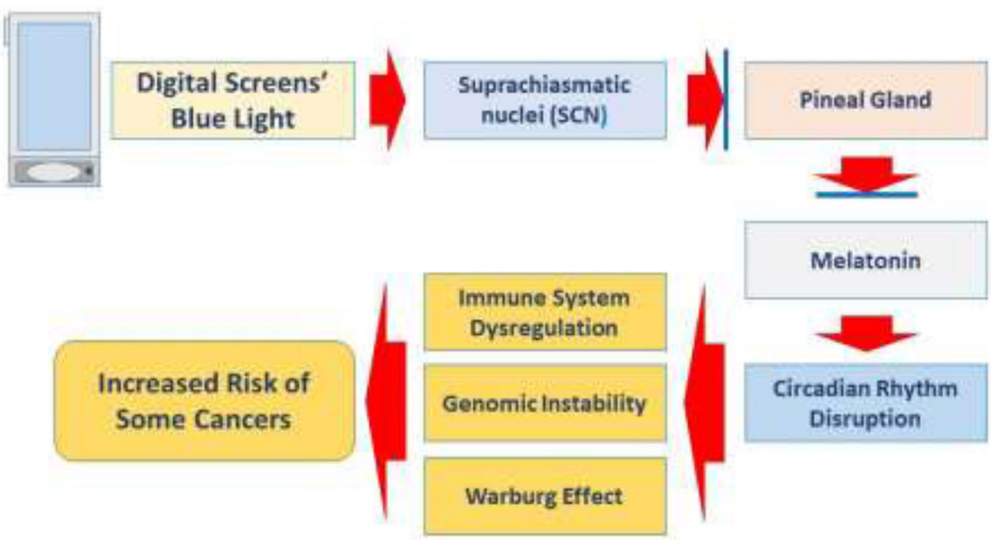

Figure 1: The short wavelength blue ligh emitted from digital screens can increase the risk of some cancers through affecting the melatonin level and biological rhythms. [This figure is modified from the original figure which appeared in a paper by Giudice et al., Molecules 2018;23(6):1308. https://doi.org/10.3390/molecules23061308 [14]]

day since it is responsible for awareness level [24-27], regulating sleep-wake cycle, metabolism, and cognitive activity [28, 29]. Thus, its level decreases during the day due to activity and increases during the night [30, 31], so that this is a light-sensitive hormone [32, 33].

However, this hormone has the maximum and minimum level in the red and green light, respectively [13, 34]; the minimum light needed to suppress the melatonin level is considered 1000 lux [35]. Moreover, melatonin decreases and reaches the time of day for people exposed to bright light during the night [27, 33, 35-38]. Therefore, if the light becomes brighter during the night, melatonin decreases more [24]. In addition to regulation, melatonin hormone adjusts the intraocular pressure. Based on the study conducted on rabbits from New Zealand, yellow filters for blue light lead to decreased intraocular pressure [39]. Sleep disorder is a common problem in teenagers and adults [40]. According to a study carried out on 35 healthy adults, who were exposed to either blue (469 nm) or amber (578 nm) wavelength light for 30 minutes in a darkened room, followed immediately by functional magnetic resonance imaging (fMRI), the blue light group were faster in their responses on the N-back task. These participants also showed increased activation in the dorsolateral and ventrolateral prefrontal cortex compared to those in the amber light control group [41]. Wood, Rea et al. showed that the melatonin level decreased after 2 h in people exposed to light emitted from the laptop [42]. Temperature of light exposed to people affects the melatonin as well as wavelength. Furthermore, it was shown in some studies that people, who were exposed to high-temperature light, had higher levels of awareness, especially children and teenagers [36, 43, 44]. In accordance with a study carried out by Lee Matsumori et al., for children and adults exposure to 3000-6200 K light with 6200 K resulted in suppression of melatonin secretion in children at night, more than adults, and also blue light emitted from LED was more effective [45]. Thus, based on the findings, it is better to use low-temperature light at night since high-temperature light leads to sleep disorders. Furthermore, 16 healthy women were exposed to lights with 2700-6500 K temperature; people exposed to light with 6500 K temperature had less awareness compared to the others [31].

The question is whether exposure to bright light can cause an increase and decrease in awareness and drowsiness, respectively, as caffeine. The use of caffeine is common in the world, so that many studies on it show that caffeine has the same effects as light on behavior and personality [46]. According to studies carried out on the light and caffeine separately and comparatively, there was a decrease in the level of melatonin and body temperature for people who used 200 mg caffeine two times a night or those who were exposed to light with an intensity more than 2000 lux.

A study found that caffeine intake and bright light exposure, both individually and combined, suppressed melatonin and attenuated the normal nighttime drop in temperature [47].

The question is why the effects of light are less on adults, especially old people, in comparison with children, especially kids? Does the brain lose excitability during the time or are there other factors to make this stability? Increasing age was associated with changes in the brain function, and the most important change reduces the ipRGCs cells [48]. Based on the studies carried out so far, reduced cells, which are responsible for the non-visual response of the brain [49, 50], result in delivering low light into SCN [51-53]. Age-related disrupted sleep is linked to changes in the timing of circadian rhythms, with studies suggesting decreased sensitivity of the aging circadian pacemaker to light [54]. In this paper, we aimed to review the bio-effects of exposure to blue light on human cognitive functions and vision quality. Moreover, studies indicating a potential link between exposure to blue light from digital screens and an increased risk of breast cancer are also reviewed.

Discussion

The effective factor of light

Studies that have been carried out reveal that there are three important factors affecting our response to light, namely wavelength, radiation duration, and light intensity. These factors control our cognitive functions and tasks [13, 55-58].

The effective factor of wavelength

Based on some studies carried out on radiation transmitted to human naturally or artificially during the day, short-wavelength visible lights (<500 nm) in comparison with long-wavelength ones (>500 nm) caused drowsiness [7, 15, 36, 59, 60] and awareness to decrease and increase, respectively [7, 61, 62]. Blue light, with 460 nm, is considered as light with a short wavelength. The shorter the wavelength, the higher the energy. It is revealed that blue light has more detrimental effects on the light receptor cell in comparison with green and white lights [63]. In the past, the only source for blue light was the sun; however, nowadays, there have been many sources, including laptops, digital TVs, and computers, the most important of which are smartphones and laptops [64, 65]. The studies show that the use of systems mentioned above in the evening affects sleep, waking, health, and reaction time [60, 66-68].

Scholkmann et al. conducted a study on 14 healthy adults exposed to red, green, and blue lights to evaluate the effect of light on the brain hemodynamic system at the visual cortex (VC) and pre-frontal cortex (PFC) using the fNIRS technique. Results obtained are as follows: **1)** all kinds of light have effects on the VC and the only light, impacting the PFC, is blue, **2)** the activity of heartbeat depends on light, and **3)** brain hemodynamic response and rate changes depend on the gender [69]. It is worth noting that the daily exposure to short wavelength blue light has been reported to be involved in modulating functional brain responses within the amygdala and PFC [70]. The PFC is associated with a variety of higher cognitive functions [71]. The significant role of PFC in personality development is well documented. Some studies show that the cognitive and emotional functions of the PFC develop in remarkable synchrony with its structural development [72]. It has been shown that people exposed to red light in the early night have better sleep quality [10].

The effect of intensity and duration of irradiation

The fact that humans are sensitive to light means that even small changes in the amount of light in a room (usually between 90-180 lux) can greatly affect how alert they feel and their corresponding brain activity during the early part of the night [73]. Many studies were done on the importance of exposure time and light intensity since researchers did not know which one (exposure time and light intensity) was more important. In a study, 56 healthy adults were exposed to bright and poor light in different times and intensities, including 1, 2, and 3 h and 2000, 4000, and 8000 lux, respectively. Exposure time was more important than light intensity. Therefore, it was effective to use moderate light for a long time to do phototherapy for people suffering from sleep disorders [56].

Another question asked is whether light intensity has an effect on the body temperature. Melatonin levels were investigated on 15 people at pre-and post-exposure with light intensity of 500, 1000, and 5000 Lux during 1700-2500 h. Findings showed that 500 lx could be considered as the threshold for significant melatonin suppression, temperature enhancement, and increased alertness [74]. High awareness and short response time were made at high-temperature light like daytime temperature (2568 k) [75]. Similarly, children exposed to blue light with 1000-lux intensity during less than 1 h are able to answer the mathematical questions better and have shorter reaction times in comparison with people exposed to red light with the same properties [7]. People were exposed to blue light and then asked mental and mathematical tests; results obtained using fMRI showed they had more mind activity and answered computational questions faster than others did [62, 76-78].

The effect of shift working

Night-shift working can cause synchronization of biological clock and sleep-wake cycle to be lost; thus, drowsiness increases and efficiency decreases. On the other hand, there are some problems due to daytime sleep and the body wants to get ready for work [79-83]. It has been nowadays called night-shift working [84]. Studies conducted on people with night-shift working revealed that people who are exposed to blue light 500 lux with 7 h night-shift working had less drowsiness and more awareness [7]. Based on the studies carried out by Campbell et al. on 25 healthy adults exposed to light with 8 h night shift, it was revealed that people exposed to 1000 lux light had more awareness [61]. Moreover, it has been revealed that workers, wearing blue light filter sunglasses, have been suffering fewer sleep disorders [85, 86].

Filtration

The maximum injury to the eyes can be caused by the exposure to short-wavelength light. According to advancements in the electronic industry, there are some theories about the effects of filters such as the advantageous or disturbing effects of filters. Filters considered as lenses are of three types: spectacle lenses utilized in glasses, contact lenses, and intra-ocular lenses.

There was no significant difference in the criteria showing the effect of digital systems on the eyes. Other studies show that glasses with filtered blue light are useful to prevent blue light, especially at night and before sleeping [87]. A study on 48 healthy adults exposed to blue light emitted from smartphones indicated that the use of smartphones without filters caused delayed sleep-phase disorder (DSPD) about 20.84±9.15 min; however, blue and amber filters cause DSPDs about 15.26±1.04 min and 26.33±1.59 min, respectively. Because blue light suppresses melatonin, an amber filter probably improved sleep via melatonin secretion [60]. Furthermore, in a study, the students were asked who got into the college and suffered from DSPDs, to use glasses with a blue filter while working with digital systems at night. According to the results, sleep hours, and mental and emotional activities had an improvement [7, 88].

One of the most important questions, which has been posed recently, is whether lens replacement leads to damage to the retina in eyes surgery such as cataract surgery, which is more common [89-91]. It has been concluded that a new lens causes the retina to attract more light in lens replacement for cataract surgery. There are different lenses which decrease this damage; thus, it would be better to use a lens which filters the UV light [92-94].

In a study, two groups, including young and old people with natural lens (NL) and second lens after cataract surgery, multifocal and/or toric intraocular lenses (IOLs), were exposed to blue and orange lights after cataract surgery. According to the results, blue light causes cognitive activities of the brain to be balanced, especially in the hippocampus, singular and frontal cortex. However, no difference was seen between IOL and NL. Based on regression analysis, brain interactions were not related to the age for different lights in old age [95].

Lenses that filter blue light may prevent the detrimental macular changes of the retina. There are some studies, answering important questions such as: based on the effects of blue light, can the lens which filters the blue light be the best choice now? or do blue light filters affect people's sight at night? The balance between light receptors and light protection is important [96-98].

Studies carried out so far show that the use of these lenses not only do not cause any changes in eye vision but also are the best choice for people with risk of macular degeneration [90, 99-102], which occurs with increasing age in many advanced societies [103-106]. The problem of driving with the high light condition was addressed using lenses with blue filters [107, 108]. However, filtering light causes some defects in people's vision, including a disorder of color perception and adjusting rhythm hours, and the poor performance of low light condition [109, 110]. Eyeglasses with UV filtered lenses work in wavelengths between 415 and 455 nm, and this range can show detrimental effects of blue light. These glasses have more advantages in comparison with intraocular lenses, including filtering a part of the spectrum and passing another part of it [111, 112].

The results of all studies mentioned above are summarized in Table 1.

The characteristics of blue light, such as irradiation duration, light intensity, and wavelength, affect performing tasks and cognitive functions. Based on the results reviewed in this paper, blue light is associated with more detrimental effects compared to other wavelengths. Moreover, exposure time seems to be of more crucial importance compared to light intensity. Individuals exposed to blue light at intensity of 500 lux during 7 h night-shift working had more awareness and less drowsiness. Moreover, based on studies carried out on students who suffered from DSPDs and wore glasses with blue filters during working with digital systems at night, sleep hours, emotional and mental activity were improved.

ALAN increases the Risk of Breast and Prostate Cancers

A study conducted by Mortazavi et al. suggests that exposure to blue light emitted from digital screens, particularly at night, can increase the risk of breast cancer. The study used machine learning models to predict breast cancer risk in women exposed to blue light from digital screens [122]. According to a study published in the International Journal of Basic and Medical Sciences, women with hereditary breast cancer predispositions should avoid using their smartphones, tablets, and laptops at night. The study predicted that short-wavelength visible light from these devices can disrupt the secretion of melatonin and cause circadian rhythm disruption, which can increase the risk of breast and ovarian cancers in women with mutations in the BRCA1 and BRCA2 genes [123]. SAR Mortazavi and his colleagues have studied the health effects of blue light over the past several years [124-130]. To reduce the risk of breast cancer in women with hereditary predispositions, AR Mortazavi and SMJ Mortazavi have recommended to avoid exposure to light at night, including domestic light and light from digital screens such as smartphones, tablets, and laptops.

It is worth noting that exposure to light at night can disrupt the secretion of melatonin and cause circadian rhythm disruption, which can increase the risk of breast cancer. A case-control study on 894 healthy controls and 211 patients with breast cancer showed that excessive smartphone use significantly increased the risk of breast cancer, particularly for participants with smartphone addiction, a close distance between the breasts and smartphone, and the habit of smartphone use before bedtime [131]. Women who work or are exposed to high levels of light at night, such as factory workers and doctors, are also at increased risk of breast cancer. A study conducted by Harvard scientists on 3,549 breast cancer cases over 2,187,425 person-years, [132] showed that exposure to residential outdoor light at night could contribute to invasive breast cancer risk. Moreover, a systematic review and metaanalysis showed that indoor exposure to light at night was associated with 13% higher risk of breast cancer [133]. An ecological study also showed that artificial light at night was significantly associated with lung,

Table 1: Summary of the studies conducted on the health effects of exposure to blue light

Author(s)	Factor	Sex	Participant's Number	Results
Kozaki, et al. [33]	Effect of wavelength	Male	12	There was not any noticeable difference in concentration of melatonin before and after exposure to nigh-time light correlated to bluish white light, for individuals involved in the study and exposed to conditions of different light.
Cajochen, et al. [13]		Male	10	In the late evening, exposure to 2 h of monochromatic light with 460 nm led to a noticeable suppression of melatonin in comparison with 550 nm monochromatic light associated with heart rate, a great warning response and incremental temperature of core body.
Killgore, et al. [30]		-	26	For individuals exposed to a 30min of amber light and blue light, and followed by functional MRI throughout working memory, there was no significant difference in levels of melatonin in the morning at the group level. There was a decrease in salivary melatonin for individuals, which was associated with great increases in activation, within the left dorso-medial in addition to right inferior lateral prefrontal cortex.
Vandewalle, et al. [59]		-	17	For individuals who listened to emotional as well as neutral vocal stimuli in addition to being exposed to changing 40s of green or blue ambient light, there was an increase in reply to emotional stimuli in the area of the voice of the temporal cortex in addition to the hippo-campus due to blue light.
Alkozei, et al. [78]		-	30	For individuals who received blue light, it was revealed that there was noticeable recall of long-delay verbal compared to those who were exposed to amber light.
Vandewalle, et al. [113]		-	27	The impacts of 1 min of low-intensity blue as well as green lights exposure were compared based on responses of the brain. After sleep, blue light, in the morning, in comparison with green light, causes an increase in brain responses in the ventrolateral and dorsolateral prefrontal cortex in addition to the intraparietal sulcus.
Cajochen, et al. [73]	Effect of light intensity, duration, and tem-perature	Male & female	23	Individuals involved in the study were exposed to illuminances, which ranged from 3 to 9100 lux for 6.5 h during the early biological nigh, after getting exposed to <3 lux for many hours. There was a decrease in EEG activity in the frequencies of theta-alpha and self-reported sleepiness.
Te Kulve, et al. [31]		female	16	Individuals involved in the study were exposed in two parts, including 2700K and 6500K light (both 55 lx). Reaction time was lower for 6500K exposure; however, the temperature of the body core was higher under 6500 K. Reaction time was related to heat loss although this relation did not clarify why the reaction time was for 2700 K.
Smolders and de Kort [43]		-	30	Results revealed there was no significant activating and even subtle performance degrading effects in the relatively high related color temperature (2700 K vs. 6000 K, 500 lx) condition but higher subjective importance in condition of the 6000 K in the morning. Participants involved in the study registered their mood in addition to the light settings as less positive in the 6000 K vs. 2700 K condition.
Chellappa, et al. [114]		male	16	For individuals involved in the study and exposed to the light of 40 lux at 6500K and at 2500K for 2 hours in the evening, exposure to light at 6500K made greater melatonin suppression associated with improved subjective warning
Dai, et al. [115]		male	12	For individuals involved in the study and exposed to changing levels of intensity of light and quantity, containing exposure to white and blue LEDs, there was non-visual effects of pulsed light on physiological function established not by quantity but the emitted light intensity, with relatively higher levels of intensity, which produce more noticeable physiological changes.

Author(s)	Factor	Sex	Participant's Number	Results
Sasseville and Hébert [85]		-	4	Individuals involved in our study and exposed to ambient blue-green light as well as light throughout various times, blue-blockers had to be used outside after the night shift. At least, melatonin of 3 individuals involved in the study had moved by 2 h. As there was an increase in the performance at the fourth night, an enhancement in parameters of subjective vigilance as well as sleep from the third night was observed.
Thorne, et al. [116]		male	10	Individuals, who worked from 18:00-6:00 h had a 6-sulphatoxymelatonin acrophase of 11.7±0.77 h (mean±SEM, decimal hours), although it was noticeably 14.6±0.55 h (p=0.01) for shift workers who worked 19:00-07:00 h. Circadian phase was later; in addition, objective sleep was shorter with the 19:00-07:00 h compared to the 18:00-06:00 h shift plan.
Gumenyuk, et al. [117]	effect of light on shift workers	-	10	5 asymptomatic night workers in addition to night shift workers, who met diagnostic criteria during shift work disorder, were involved in the study, and stayed in a room, which was dim light and private during the study period of 25 h.
Grundy, et al. [118]		female	61	Concentrations of melatonin as well as light intensity were measured. There was not any noticeable relationship between melatonin as well as sleep duration, and also, there was no similar relationship between melatonin as well as physical activity. Based on the analysis of the levels of salivary melatonin, the circadian rhythms did not change for night workers, which means production of peak melatonin occurs at night.
Rahman, et al. [119]		-	9	There was a random selection of participants to receive either filtered light or standard indoor light at night shift. Levels of salivary melatonin as well as alertness were investigated every 2 h at the first night shift of every study period. At the baseline night polysomnography, all sleep efficiency and time sleep were noticeably declined and intervening wake times noticeably had an increase with a mean 40 min than baseline. During the night and both conditions, subjective sleepiness had an increase.
Gray, et al. [107]		-	34	With associated glare, the margin of safety was statistically noticeably greater in the study group compared to the control group. In the comparison glare and no-glare conditions, the study group showed noticeably lower glare susceptibility and effect on intersection approach speech compared to the control group in addition to fewer collisions with the oncoming car.
Gray, et al. [108]		-	33	For glare, patients who took IOLs test had noticeably more safety margins compared to those taking control IOLs and noticeably lower glare susceptibility. In glare and no-glare situations, patients with IOLs test showed noticeably lower glare susceptibility compared to those with control IOLs.
Henriksen, et al. [120]	effect of blue light filtration	-	-	The individuals involved in the study were accidently allocated to put on blue blocking (BB) glasses or placebo (clear glasses) from 18:00 to 8:00 h. The mean sleep efficiency of the BB group was noticeably higher than the placebo group.
Janku, et al. [121]		Male & female	30	Patients finished a program of CBT-I group therapy with groups accidentally assigned to condition of "active" (glasses with blue-light filtering) or condition of "placebo" (glasses without any properties of filtering). When the comparison of results in both groups was done before and after treatment, separately, important differences were seen also in the active group. No significant differences were detected in the placebo group. In addition, in active group, there was a marked decrease of subjective sleep latency and an increase of subjective whole sleep time without any changes in objective sleep length of time, which, in the placebo group, was noticeably shortened.

MRI: Magnetic Resonance Imaging, EEG: Electroencephalogram, LEDs: Light Emitting Diodes, SEM: Scanning Electron Microscope, IOLs: Intraocular Lenses, CBT-I: Cognitive Behavioral Therapy for Insomnia breast, colorectal, and prostate cancers [134].

Conclusion

Due to factors such as increasing use of digital screens at night and urban light pollution, modern life is linked to significant interruptions in light-dark cycles. Blue light from digital screens is associated with a wide variety of problems ranging from macular degeneration, and cataracts to poor sleep, mental health problems and even increased risk for some cancers. Given this consideration, understanding the effects of exposure to blue light on the circadian ryhtm is of crucial importance. More research is needed to fully comprehend the relationship between blue light exposure and adverse health effects, such as the risk of breast cancer.

Authors' Contribution

SMJ. Mortazavi designed the review study. SMJ. Mortazavi, M. Haghani and SAR. Mortazavi supervised the review process. M. Haghani, S. Abbasi, L. Abdoli and SF. Shams have equally contributed to this work. All authors have contributed to the gathering of the data, interpretation of the findings, and writing/reviewing of the current manuscript and read, modified, and approved the final version of the manuscript.

Conflict of Interest

SMJ. Mortazavi, as the Editorial Board Member, was not involved in the peer-review and decision-making processes for this manuscript.

References

1. Edgar RS, Green EW, Zhao Y, Van Ooijen G, Olmedo M, Qin X, et al. Peroxiredoxins are conserved markers of circadian rhythms. *Nature.* 2012;**485**(7399):459-64. doi: 10.1038/nature11088. PubMed PMID: 22622569. PubMed PMCID: PMC3398137.
2. Ko CH, Takahashi JS. Molecular components of the mammalian circadian clock. *Hum Mol Genet.* 2006;**15**(suppl_2):R271-7. doi: 10.1093/hmg/ddl207. PubMed PMID: 16987893.
3. Gooley JJ, Lu J, Fischer D, Saper CB. A broad role for melanopsin in nonvisual photoreception. *J Neurosci.* 2003;**23**(18):7093-106. doi: 10.1523/JNEUROSCI.23-18-07093.2003. PubMed PMID: 12904470. PubMed PMCID: PMC6740653.
4. Yamazaki S, Numano R, Abe M, Hida A, Takahashi R, Ueda M, et al. Resetting central and peripheral circadian oscillators in transgenic rats. *Science.* 2000;**288**(5466):682-5. doi: 10.1126/science.288.5466.682. PubMed PMID: 10784453.
5. Yoo SH, Yamazaki S, Lowrey PL, Shimomura K, Ko CH, Buhr ED, et al. PERIOD2::LUCIFERASE real-time reporting of circadian dynamics reveals persistent circadian oscillations in mouse peripheral tissues. *Proc Natl Acad Sci U S A.* 2004;**101**(15):5339-46. doi: 10.1073/pnas.0308709101. PubMed PMID: 14963227. PubMed PMCID: PMC397382.
6. Gronfier C. The good blue and chronobiology: light and non-visual functions. International Review of Ophthalmic Optics, N68, Points de Vue; 2013.
7. Studer P, Brucker JM, Haag C, Van Doren J, Moll GH, Heinrich H, Kratz O. Effects of blue- and red-enriched light on attention and sleep in typically developing adolescents. *Physiol Behav.* 2019;**199**:11-19. doi: 10.1016/j.physbeh.2018.10.015. PubMed PMID: 30381244.
8. Brown SA, Zumbrunn G, Fleury-Olela F, Preitner N, Schibler U. Rhythms of mammalian body temperature can sustain peripheral circadian clocks. *Curr Biol.* 2002;**12**(18):1574-83. doi: 10.1016/s0960-9822(02)01145-4. PubMed PMID: 12372249.
9. Marshall L, Helgadóttir H, Mölle M, Born J. Boosting slow oscillations during sleep potentiates memory. *Nature.* 2006;**444**(7119):610-3. doi: 10.1038/nature05278. PubMed PMID: 17086200.
10. Nishida M, Pearsall J, Buckner RL, Walker MP. REM sleep, prefrontal theta, and the consolidation of human emotional memory. *Cereb Cortex.* 2009;**19**(5):1158-66. doi: 10.1093/cercor/bhn155 PubMed PMID: 18832332. PubMed PMCID: PMC2665156.
11. Palmer CA, Alfano CA. Sleep and emotion regulation: An organizing, integrative review. *Sleep Med Rev.* 2017;**31**:6-16. doi: 10.1016/j.smrv.2015.12.006. PubMed PMID: 26899742.
12. Metz AJ, Klein SD, Scholkmann F, Wolf U. Continuous coloured light altered human brain haemodynamics and oxygenation assessed by systemic physiology augmented functional near-infrared spectroscopy. *Sci Rep.* 2017;**7**(1):10027. doi: 10.1038/s41598-017-09970-z. PubMed PMID: 28855556. PubMed PMCID: PMC5577215.
13. Cajochen C, Münch M, Kobialka S, Kräuchi K,

Steiner R, Oelhafen P, et al. High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light. *J Clin Endocrinol Metab*. 2005;**90**(3):1311-6. doi: 10.1210/jc.2004-0957. PubMed PMID: 15585546.

14. Giudice A, Crispo A, Grimaldi M, Polo A, Bimonte S, Capunzo M, et al. The Effect of Light Exposure at Night (LAN) on Carcinogenesis via Decreased Nocturnal Melatonin Synthesis. *Molecules.* 2018;**23**(6):1308. doi: 10.3390/molecules23061308. PubMed PMID: 29844288. PubMed PMCID: PMC6100442.
15. Vandewalle G, Maquet P, Dijk DJ. Light as a modulator of cognitive brain function. *Trends Cogn Sci.* 2009;**13**(10):429-38. doi: 10.1016/j.tics.2009.07.004. PubMed PMID: 19748817.
16. Daneault V, Hébert M, Albouy G, Doyon J, Dumont M, Carrier J, Vandewalle G. Aging reduces the stimulating effect of blue light on cognitive brain functions. *Sleep*. 2014;**37**(1):85-96. doi: 10.5665/sleep.3314. PubMed PMID: 24381372. PubMed PMCID: PMC3865352.
17. Katsuura T, Yasuda T, Shimomura Y, Iwanaga K. Effects of monochromatic light on time sense for short intervals. *J Physiol Anthropol.* 2007;**26**(2):95-100. doi: 10.2114/jpa2.26.95. PubMed PMID: 17435350.
18. Hattar S, Liao HW, Takao M, Berson DM, Yau KW. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. *Science.* 2002;**295**(5557):1065-70. doi: 10.1126/science.1069609. PubMed PMID: 11834834. PubMed PMCID: PMC2885915.
19. Provencio I, Jiang G, De Grip WJ, Hayes WP, Rollag MD. Melanopsin: An opsin in melanophores, brain, and eye. *Proc Natl Acad Sci U S A*. 1998;**95**(1):340-5. doi: 10.1073/pnas.95.1.340. PubMed PMID: 9419377. PubMed PMCID: PMC18217.
20. Alkozi HA, Wang X, Perez De Lara MJ, Pintor J. Presence of melanopsin in human crystalline lens epithelial cells and its role in melatonin synthesis. *Exp Eye Res*. 2017;**154**:168-76. doi: 10.1016/j.exer.2016.11.019. PubMed PMID: 27914990.
21. Bellingham J, Foster RG. Opsins and mammalian photoentrainment. *Cell Tissue Res*. 2002;**309**(1):57-71. doi: 10.1007/s00441-002-0573-4. PubMed PMID: 12111537.
22. Baver SB, Pickard GE, Sollars PJ, Pickard GE. Two types of melanopsin retinal ganglion cell differentially innervate the hypothalamic suprachiasmatic nucleus and the olivary pretectal nucleus. *Eur J Neurosci.* 2008;**27**(7):1763-70. doi: 10.1111/j.1460-9568.2008.06149.x. PubMed PMID: 18371076.
23. Wurtman RJ, Axelrod J, Phillips LS. Melatonin Synthesis In The Pineal Gland: Control By Light. *Science.* 1963;**142**(3595):1071-3. doi: 10.1126/science.142.3595.1071. PubMed PMID: 14068225.
24. McIntyre IM, Norman TR, Burrows GD, Armstrong SM. Human melatonin suppression by light is intensity dependent. *J Pineal Res*. 1989;**6**(2):149-56. doi: 10.1111/j.1600-079x.1989.tb00412.x. PubMed PMID: 2915324.
25. Rajaratnam SM, Middleton B, Stone BM, Arendt J, Dijk DJ. Melatonin advances the circadian timing of EEG sleep and directly facilitates sleep without altering its duration in extended sleep opportunities in humans. *J Physiol.* 2004;**561**(Pt 1):339-51. doi: 10.1113/jphysiol.2004.073742. PubMed PMID: 15459246. PubMed PMCID: PMC1665336.
26. Souman JL, Tinga AM, Te Pas SF, Van Ee R, Vlaskamp BNS. Acute alerting effects of light: A systematic literature review. *Behav Brain Res*. 2018;**337**:228-39. doi: 10.1016/j.bbr.2017.09.016. PubMed PMID: 28912014.
27. Dollins AB, Lynch HJ, Wurtman RJ, Deng MH, Lieberman HR. Effects of illumination on human nocturnal serum melatonin levels and performance. *Physiol Behav.* 1993;**53**(1):153-60. doi: 10.1016/0031-9384(93)90024-a. PubMed PMID: 8434055.
28. Czeisler CA, Weitzman ED, Moore-Ede MC, Zimmerman JC, Knauer RS. Human sleep: its duration and organization depend on its circadian phase. *Science.* 1980;**210**(4475):1264-7. doi: 10.1126/science.7434029. PubMed PMID: 7434029.
29. Scheer FA, Hilton MF, Mantzoros CS, Shea SA. Adverse metabolic and cardiovascular consequences of circadian misalignment. *Proc Natl Acad Sci U S A*. 2009;**106**(11):4453-8. doi: 10.1073/pnas.0808180106. PubMed PMID: 19255424. PubMed PMCID: PMC2657421.
30. Killgore WDS, Kent HC, Knight SA, Alkozei A. Changes in morning salivary melatonin correlate with prefrontal responses during working memory performance. *Neuroreport.* 2018;**29**(6):488-94. doi: 10.1097/WNR.0000000000001002. PubMed PMID: 29528974.
31. Te Kulve M, Schlangen L, Schellen L, Souman JL, Van Marken Lichtenbelt W. Correlated colour temperature of morning light influences alertness and body temperature. *Physiol Behav*. 2018;**185**:1-13. doi: 10.1016/j.physbeh.2017.12.004. PubMed PMID: 29223712.
32. McGlashan EM, Poudel GR, Vidafar P, Drummond SPA, Cain SW. Imaging Individual Differences in

the Response of the Human Suprachiasmatic Area to Light. *Front Neurol.* 2018;**9**:1022. doi: 10.3389/fneur.2018.01022. PubMed PMID: 30555405. PubMed PMCID: PMC6281828.

33. Kozaki T, Kubokawa A, Taketomi R, Hatae K. Light-induced melatonin suppression at night after exposure to different wavelength composition of morning light. *Neurosci Lett.* 2016;**616**:1-4. doi: 10.1016/j.neulet.2015.12.063. PubMed PMID: 26777427.
34. Drozdova A, Okuliarova M, Zeman M. The effect of different wavelengths of light during incubation on the development of rhythmic pineal melatonin biosynthesis in chick embryos. *Animal.* 2019;**13**(8):1635-40. doi: 10.1017/S1751731118003695. PubMed PMID: 30614433.
35. Lewy AJ, Wehr TA, Goodwin FK, Newsome DA, Markey SP. Light suppresses melatonin secretion in humans. *Science.* 1980;**210**(4475):1267-9. doi: 10.1126/science.7434030. PubMed PMID: 7434030.
36. Badia P, Myers B, Boecker M, Culpepper J, Harsh JR. Bright light effects on body temperature, alertness, EEG and behavior. *Physiol Behav.* 1991;**50**(3):583-8. doi: 10.1016/0031-9384(91)90549-4. PubMed PMID: 1801013.
37. Green A, Cohen-Zion M, Haim A, Dagan Y. Evening light exposure to computer screens disrupts human sleep, biological rhythms, and attention abilities. *Chronobiol Int.* 2017;**34**(7):855-65. doi: 10.1080/07420528.2017.1324878. PubMed PMID: 28548897.
38. Gooley JJ, Chamberlain K, Smith KA, Khalsa SB, Rajaratnam SM, Van Reen E, et al. Exposure to room light before bedtime suppresses melatonin onset and shortens melatonin duration in humans. *J Clin Endocrinol Metab.* 2011;**96**(3):E463-72. doi: 10.1210/jc.2010-2098. PubMed PMID: 21193540. PubMed PMCID: PMC3047226.
39. Lledó VE, Alkozi HA, Pintor J. Yellow Filter Effect on Melatonin Secretion in the Eye: Role in IOP Regulation. *Curr Eye Res.* 2019;**44**(6):614-8. doi: 10.1080/02713683.2019.1570276. PubMed PMID: 30640554.
40. Gradisar M, Gardner G, Dohnt H. Recent worldwide sleep patterns and problems during adolescence: a review and meta-analysis of age, region, and sleep. *Sleep Med.* 2011;**12**(2):110-8. doi: 10.1016/j.sleep.2010.11.008. PubMed PMID: 21257344.
41. Alkozei A, Smith R, Pisner DA, Vanuk JR, Berryhill SM, Fridman A, et al. Exposure to Blue Light Increases Subsequent Functional Activation of the Prefrontal Cortex During Performance of a Working Memory Task. *Sleep.* 2016;**39**(9):1671-80. doi: 10.5665/sleep.6090. PubMed PMID: 27253770. PubMed PMCID: PMC4989256.
42. Wood B, Rea MS, Plitnick B, Figueiro MG. Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. *Appl Ergon.* 2013;**44**(2):237-40. doi: 10.1016/j.apergo.2012.07.008. PubMed PMID: 22850476.
43. Smolders KC, De Kort YA. Investigating daytime effects of correlated colour temperature on experiences, performance, and arousal. *Journal of Environmental Psychology.* 2017;**50**:80-93. doi: 10.1016/j.jenvp.2017.02.001.
44. Shamsul BM, Sia CC, Ng YG, Karmegan K. Effects of light's colour temperatures on visual comfort level, task performances, and alertness among students. *American Journal of Public Health Research.* 2013;**1**(7):159-65. doi: 10.12691/ajphr-1-7-3.
45. Lee SI, Matsumori K, Nishimura K, Nishimura Y, Ikeda Y, Eto T, Higuchi S. Melatonin suppression and sleepiness in children exposed to blue-enriched white LED lighting at night. *Physiol Rep.* 2018;**6**(24):e13942. doi: 10.14814/phy2.13942. PubMed PMID: 30556352. PubMed PMCID: PMC6295443.
46. Smith A. Effects of caffeine on human behavior. *Food Chem Toxicol.* 2002;**40**(9):1243-55. doi: 10.1016/s0278-6915(02)00096-0. PubMed PMID: 12204388.
47. Wright KP Jr, Badia P, Myers BL, Plenzler SC, Hakel M. Caffeine and light effects on nighttime melatonin and temperature levels in sleep-deprived humans. *Brain Res.* 1997;**747**(1):78-84. doi: 10.1016/s0006-8993(96)01268-1. PubMed PMID: 9042530.
48. Semo M, Peirson S, Lupi D, Lucas RJ, Jeffery G, Foster RG. Melanopsin retinal ganglion cells and the maintenance of circadian and pupillary responses to light in aged rodless/coneless (rd/rd cl) mice. *Eur J Neurosci.* 2003;**17**(9):1793-801. doi: 10.1046/j.1460-9568.2003.02616.x. PubMed PMID: 12752778.
49. Güler AD, Ecker JL, Lall GS, Haq S, Altimus CM, Liao HW, et al. Melanopsin cells are the principal conduits for rod-cone input to non-image-forming vision. *Nature.* 2008;**453**(7191):102-5. doi: 10.1038/nature06829. PubMed PMID: 18432195. PubMed PMCID: PMC2871301.
50. Tsai JW, Hannibal J, Hagiwara G, Colas D, Ruppert E, Ruby NF, et al. Melanopsin as a sleep modulator: circadian gating of the direct effects of light on sleep and altered sleep homeostasis in Opn4(-

/-) mice. *PLoS Biol.* 2009;**7**(6):e1000125. doi: 10.1371/journal.pbio.1000125. PubMed PMID: 19513122. PubMed PMCID: PMC2688840.

51. Lupi D, Semo M, Foster RG. Impact of age and retinal degeneration on the light input to circadian brain structures. *Neurobiol Aging.* 2012;**33**(2):383-92. doi: 10.1016/j.neurobiolaging.2010.03.006. PubMed PMID: 20409612.
52. Brainard GC, Rollag MD, Hanifin JP. Photic regulation of melatonin in humans: ocular and neural signal transduction. *J Biol Rhythms.* 1997;**12**(6):537-46. doi: 10.1177/074873049701200608. PubMed PMID: 9406028.
53. Charman WN. Age, lens transmittance, and the possible effects of light on melatonin suppression. *Ophthalmic Physiol Opt.* 2003;**23**(2):181-7. doi: 10.1046/j.1475-1313.2003.00105.x. PubMed PMID: 12641706.
54. Scheuermaier KD, Lee JH, Duffy JF. Phase Shifts to a Moderate Intensity Light Exposure in Older Adults: A Preliminary Report. *J Biol Rhythms.* 2019;**34**(1):98-104. doi: 10.1177/0748730418818655. PubMed PMID: 30554544. PubMed PMCID: PMC9217104.
55. Chang AM, Santhi N, St Hilaire M, Gronfier C, Bradstreet DS, Duffy JF, et al. Human responses to bright light of different durations. *J Physiol.* 2012;**590**(13):3103-12. doi: 10.1113/jphysiol.2011.226555. PubMed PMID: 22526883. PubMed PMCID: PMC3406393.
56. Dewan K, Benloucif S, Reid K, Wolfe LF, Zee PC. Light-induced changes of the circadian clock of humans: increasing duration is more effective than increasing light intensity. *Sleep.* 2011;**34**(5):593-9. doi: 10.1093/sleep/34.5.593. PubMed PMID: 21532952. PubMed PMCID: PMC3079938.
57. Lockley SW, Brainard GC, Czeisler CA. High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *J Clin Endocrinol Metab.* 2003;**88**(9):4502-5. doi: 10.1210/jc.2003-030570. PubMed PMID: 12970330.
58. Cajochen C. Alerting effects of light. *Sleep Med Rev.* 2007;**11**(6):453-64. doi: 10.1016/j.smrv.2007.07.009. PubMed PMID: 17936041.
59. Vandewalle G, Schwartz S, Grandjean D, Wuillaume C, Balteau E, Degueldre C, et al. Spectral quality of light modulates emotional brain responses in humans. *Proc Natl Acad Sci U S* A. 2010;**107**(45):19549-54. doi: 10.1073/pnas.1010180107. PubMed PMID: 20974959. PubMed PMCID: PMC2984196.
60. Mortazavi SAR, Parhoodeh S, Hosseini MA, Arabi H, Malakooti H, Nematollahi S, et al. Blocking Short-Wavelength Component of the Visible Light Emitted by Smartphones' Screens Improves Human Sleep Quality. *J Biomed Phys Eng.* 2018;**8**(4):375-80. PubMed PMID: 30568927. PubMed PMCID: PMC6280115.
61. Campbell SS, Dawson D. Enhancement of nighttime alertness and performance with bright ambient light. *Physiol Behav.* 1990;*48*(2):317-20. doi: 10.1016/0031-9384(90)90320-4. PubMed PMID: 2255738.
62. Lehrl S, Gerstmeyer K, Jacob JH, Frieling H, Henkel AW, Meyrer R, et al. Blue light improves cognitive performance. *J Neural Transm (Vienna).* 2007;**114**(4):457-60. doi: 10.1007/s00702-006-0621-4. PubMed PMID: 17245536.
63. Spitschan M, Lazar R, Cajochen C. Visual and non-visual properties of filters manipulating short-wavelength light. *Ophthalmic Physiol Opt.* 2019;**39**(6):459-68. doi: 10.1111/opo.12648. PubMed PMID: 31696535. PubMed PMCID: PMC6887545.
64. Kuse Y, Ogawa K, Tsuruma K, Shimazawa M, Hara H. Damage of photoreceptor-derived cells in culture induced by light emitting diode-derived blue light. *Sci Rep.* 2014;**4**:5223. doi: 10.1038/srep05223. PubMed PMID: 24909301. PubMed PMCID: PMC4048889.
65. National Sleep Foundation. Summary of Findings "Sleep in America ® poll". 2005.
66. Chinoy ED, Duffy JF, Czeisler CA. Unrestricted evening use of light-emitting tablet computers delays self-selected bedtime and disrupts circadian timing and alertness. *Physiol Rep.* 2018;**6**(10):e13692. doi: 10.14814/phy2.13692. PubMed PMID: 29845764. PubMed PMCID: PMC5974725.
67. Chang AM, Aeschbach D, Duffy JF, Czeisler CA. Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness. *Proc Natl Acad Sci U S A.* 2015;**112**(4):1232-7. doi: 10.1073/pnas.1418490112. PubMed PMID: 25535358. PubMed PMCID: PMC4313820.
68. Heo JY, Kim K, Fava M, Mischoulon D, Papakostas GI, Kim MJ, et al. Effects of smartphone use with and without blue light at night in healthy adults: A randomized, double-blind, cross-over, placebo-controlled comparison. *J Psychiatr Res.* 2017;**87**:61-70. doi: 10.1016/j.jpsychires.2016.12.010. PubMed PMID: 28017916.
69. Scholkmann F, Hafner T, Metz AJ, Wolf M, Wolf U. Effect of short-term colored-light exposure on cerebral hemodynamics and oxygenation, and systemic physiological activity. *Neurophotonics.* 2017;**4**(4):045005. doi: 10.1117/1.

NPh.4.4.045005. PubMed PMID: 29181427. PubMed PMCID: PMC5695650.

70. Alkozei A, Dailey NS, Bajaj S, Vanuk JR, Raikes AC, Killgore WD. Blue Wavelength Light and its Effects on Functional Brain Connectivity. *Biological Psychiatry.* 2020;**87**(9):S146. doi: /10.1016/j.biopsych.2020.02.388.
71. Funahashi S. Working Memory in the Prefrontal Cortex. *Brain Sci.* 2017;**7**(5):49. doi: 10.3390/brainsci7050049. PubMed PMID: 28448453. PubMed PMCID: PMC5447931.
72. Uytun MC. Development period of prefrontal cortex. In: Prefrontal Cortex. IntechOpen; 2018.
73. Cajochen C, Zeitzer JM, Czeisler CA, Dijk DJ. Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. *Behav Brain Res.* 2000;**115**(1):75-83. doi: 10.1016/s0166-4328(00)00236-9. PubMed PMID: 10996410.
74. Myers BL, Badia P. Immediate effects of different light intensities on body temperature and alertness. *Physiol Behav.* 1993;**54**(1):199-202. doi: 10.1016/0031-9384(93)90067-p. PubMed PMID: 8327605.
75. Sahin L, Wood BM, Plitnick B, Figueiro MG. Daytime light exposure: effects on biomarkers, measures of alertness, and performance. *Behav Brain Res.* 2014;**274**:176-85. doi: 10.1016/j.bbr.2014.08.017. PubMed PMID: 25131505.
76. Vandewalle G, Gais S, Schabus M, Balteau E, Carrier J, Darsaud A, et al. Wavelength-dependent modulation of brain responses to a working memory task by daytime light exposure. *Cereb Cortex.* 2007;**17**(12):2788-95. doi: 10.1093/cercor/bhm007. PubMed PMID: 17404390.
77. Vandewalle G, Collignon O, Hull JT, Daneault V, Albouy G, Lepore F, et al. Blue light stimulates cognitive brain activity in visually blind individuals. *J Cogn Neurosci.* 2013;**25**(12):2072-85. doi: 10.1162/jocn_a_00450. PubMed PMID: 23859643. PubMed PMCID: PMC4497579.
78. Alkozei A, Smith R, Dailey NS, Bajaj S, Killgore WDS. Acute exposure to blue wavelength light during memory consolidation improves verbal memory performance. *PLoS One.* 2017;**12**(9):e0184884. doi: 10.1371/journal.pone.0184884. PubMed PMID: 28922397. PubMed PMCID: PMC5602660.
79. Akerstedt T. Psychological and psychophysiological effects of shift work. *Scand J Work Environ Health.* 1990;**16**(Suppl 1):67-73. doi: 10.5271/sjweh.1819. PubMed PMID: 2189223.
80. Akerstedt T. Work hours, sleepiness and the underlying mechanisms. *J Sleep Res*. 1995;**4**(S2):15-22. doi: 10.1111/j.1365-2869.1995.tb00221.x. PubMed PMID: 10607206.
81. Eastman CI, Boulos Z, Terman M, Campbell SS, Dijk DJ, Lewy AJ. Light treatment for sleep disorders: consensus report. VI. Shift work. *J Biol Rhythms.* 1995;**10**(2):157-64. doi: 10.1177/074873049501000208. PubMed PMID: 7632989.
82. Benhaberou-Brun D, Lambert C, Dumont M. Association between melatonin secretion and daytime sleep complaints in night nurses. *Sleep*. 1999;**22**(7):877-85. doi: 10.1093/sleep/22.7.877. PubMed PMID: 10566906.
83. Dumont M, Lanctôt V, Cadieux-Viau R, Paquet J. Melatonin production and light exposure of rotating night workers. *Chronobiol Int.* 2012;**29**(2):203-10. doi: 10.3109/07420528.2011.647177. PubMed PMID: 22324558.
84. Thorpy MJ. Classification of sleep disorders. *Neurotherapeutics*. 2012;**9**(4):687-701. doi: 10.1007/s13311-012-0145-6. PubMed PMID: 22976557. PubMed PMCID: PMC3480567.
85. Sasseville A, Hébert M. Using blue-green light at night and blue-blockers during the day to improves adaptation to night work: a pilot study. *Prog Neuropsychopharmacol Biol Psychiatry*. 2010;**34**(7):1236-42. doi: 10.1016/j.pnpbp.2010.06.027. PubMed PMID: 20599459.
86. Casper RF, Rahman S. Spectral modulation of light wavelengths using optical filters: effect on melatonin secretion. *Fertil Steril.* 2014;**102**(2):336-8. doi: 10.1016/j.fertnstert.2014.06.006. PubMed PMID: 25015557.
87. Van Der Lely S, Frey S, Garbazza C, Wirz-Justice A, Jenni OG, Steiner R, et al. Blue blocker glasses as a countermeasure for alerting effects of evening light-emitting diode screen exposure in male teenagers. *J Adolesc Health.* 2015;**56**(1):113-9. doi: 10.1016/j.jadohealth.2014.08.002. PubMed PMID: 25287985.
88. Perez Algorta G, Van Meter A, Dubicka B, Jones S, Youngstrom E, Lobban F. Blue blocking glasses worn at night in first year higher education students with sleep complaints: a feasibility study. *Pilot Feasibility Stud.* 2018;**4**:166. doi: 10.1186/s40814-018-0360-y. PubMed PMID: 30410784. PubMed PMCID: PMC6211454.
89. Hayashi K, Hayashi H. Visual function in patients with yellow tinted intraocular lenses compared with vision in patients with non-tinted intraocular lenses. *Br J Ophthalmol.* 2006;**90**(8):1019-23. doi: 10.1136/bjo.2006.090712. PubMed PMID: 16597662. PubMed PMCID: PMC1857188.

90. Colombo L, Melardi E, Ferri P, Montesano G, Samir Attaalla S, Patelli F, et al. Visual function improvement using photocromic and selective blue-violet light filtering spectacle lenses in patients affected by retinal diseases. *BMC Ophthalmol*. 2017;**17**(1):149. doi: 10.1186/s12886-017-0545-9. PubMed PMID: 28830379. PubMed PMCID: PMC5568170.
91. Davison JA, Patel AS. Light normalizing intraocular lenses. *Int Ophthalmol Clin*. 2005;**45**(1):55-106. PubMed PMID: 15632528.
92. Wirtitsch MG, Schmidinger G, Prskavec M, Rubey M, Skorpik F, Heinze G, et al. Influence of blue-light-filtering intraocular lenses on color perception and contrast acuity. *Ophthalmology.* 2009;**116**(1):39-45. doi: 10.1016/j.ophtha.2008.08.035. PubMed PMID: 19118695.
93. Bandyopadhyay S, Saha M, Chakrabarti A, Sinha A. Effect on contrast sensitivity after clear, yellow and orange intraocular lens implantation. *Int Ophthalmol*. 2016;**36**(3):313-8. doi: 10.1007/s10792-015-0120-4. PubMed PMID: 26286756.
94. Alzahrani HS, Khuu SK, Roy M. Modelling the effect of commercially available blue-blocking lenses on visual and non-visual functions. *Clin Exp Optom.* 2020;**103**(3):339-46. doi: 10.1111/cxo.12959. PubMed PMID: 31441122.
95. Daneault V, Dumont M, Massé É, Forcier P, Boré A, Lina JM, et al. Plasticity in the Sensitivity to Light in Aging: Decreased Non-visual Impact of Light on Cognitive Brain Activity in Older Individuals but No Impact of Lens Replacement. *Front Physiol.* 2018;**9**:1557. doi: 10.3389/fphys.2018.01557. PubMed PMID: 30459639. PubMed PMCID: PMC6232421.
96. Downes SM. Ultraviolet or blue-filtering intraocular lenses: what is the evidence? *Eye (Lond).* 2016;**30**(2):215-21. doi: 10.1038/eye.2015.267. PubMed PMID: 26742866. PubMed PMCID: PMC4763142.
97. Li X, Kelly D, Nolan JM, Dennison JL, Beatty S. The evidence informing the surgeon's selection of intraocular lens on the basis of light transmittance properties. *Eye (Lond).* 2017;**31**(2):258-72. doi: 10.1038/eye.2016.266. PubMed PMID: 27935597. PubMed PMCID: PMC5306461.
98. Mainster MA, Sparrow JR. How much blue light should an IOL transmit? *Br J Ophthalmol*. 2003;**87**(12):1523-9. doi: 10.1136/bjo.87.12.1523. PubMed PMID: 14660465. PubMed PMCID: PMC1920564.
99. Wohlfart C, Tschuschnig K, Fellner P, Weiss K, Vidic B, El-Shabrawi Y, Ardjomand N. Visual function with blue light filter IOLs. *Klin Monbl Augenheilkd.* 2007;**224**(1):23-7. doi: 10.1055/s-2006-927275. PubMed PMID: 17260315.
100. Eperjesi F, Fowler CW, Evans BJ. The effects of coloured light filter overlays on reading rates in age-related macular degeneration. *Acta Ophthalmol Scand.* 2004;**82**(6):695-700. doi: 10.1111/j.1600-0420.2004.00371.x. PubMed PMID: 15606466.
101. Leung TW, Li RW, Kee CS. Blue-Light Filtering Spectacle Lenses: Optical and Clinical Performances. *PLoS One.* 2017;**12**(1):e0169114. doi: 10.1371/journal.pone.0169114. PubMed PMID: 28045969. PubMed PMCID: PMC5207664.
102. Niwano Y, Iwasawa A, Tsubota K, Ayaki M, Negishi K. Protective effects of blue light-blocking shades on phototoxicity in human ocular surface cells. *BMJ Open Ophthalmol.* 2019;**4**(1):e000217. doi: 10.1136/bmjophth-2018-000217. PubMed PMID: 31245609. PubMed PMCID: PMC6557184.
103. Klein R, Wang Q, Klein BE, Moss SE, Meuer SM. The relationship of age-related maculopathy, cataract, and glaucoma to visual acuity. *Invest Ophthalmol Vis Sci*. 1995;**36**(1):182-91. PubMed PMID: 7822146.
104. Taylor HR, Muñoz B, West S, Bressler NM, Bressler SB, Rosenthal FS. Visible light and risk of age-related macular degeneration. *Trans Am Ophthalmol Soc.* 1990;**88**:163-73. PubMed PMID: 2095019. PubMed PMCID: PMC1298584.
105. Winkler BS, Boulton ME, Gottsch JD, Sternberg P. Oxidative damage and age-related macular degeneration. *Mol Vis.* 1999;**5**:32. PubMed PMID: 10562656. PubMed PMCID: PMC1773059.
106. De Jong PT. Age-related macular degeneration. *N Engl J Med*. 2006;**355**(14):1474-85. doi: 10.1056/NEJMra062326. PubMed PMID: 17021323.
107. Gray R, Perkins SA, Suryakumar R, Neuman B, Maxwell WA. Reduced effect of glare disability on driving performance in patients with blue light-filtering intraocular lenses. *J Cataract Refract Surg.* 2011;**37**(1):38-44. doi: 10.1016/j.jcrs.2010.07.034. PubMed PMID: 21183098.
108. Gray R, Hill W, Neuman B, Houtman D, Potvin R. Effects of a blue light-filtering intraocular lens on driving safety in glare conditions. *J Cataract Refract Surg*. 2012;**38**(5):816-22. doi: 10.1016/j.jcrs.2011.11.047. PubMed PMID: 22520305.
109. Cuthbertson FM, Peirson SN, Wulff K, Foster RG, Downes SM. Blue light-filtering intraocular lenses: review of potential benefits and side effects. *J Cataract Refract Surg.* 2009;**35**(7):1281-97. doi: 10.1016/j.jcrs.2009.04.017. PubMed PMID: 19545821.

110. Do MT, Yau KW. Intrinsically photosensitive retinal ganglion cells. *Physiol Rev.* 2010;**90**(4):1547-81. doi: 10.1152/physrev.00013.2010. PubMed PMID: 20959623. PubMed PMCID: PMC4374737.

111. Ayaki M, Hattori A, Maruyama Y, Nakano M, Yoshimura M, Kitazawa M, et al. Protective effect of blue-light shield eyewear for adults against light pollution from self-luminous devices used at night. *Chronobiol Int.* 2016;**33**(1):134-9. doi: 10.3109/07420528.2015.1119158. PubMed PMID: 26730983.

112. Giannos SA, Kraft ER, Lyons LJ, Gupta PK. Spectral Evaluation of Eyeglass Blocking Efficiency of Ultraviolet/High-energy Visible Blue Light for Ocular Protection. *Optom Vis Sci.* 2019;**96**(7):513-22. doi: 10.1097/OPX.0000000000001393. PubMed PMID: 31274740. PubMed PMCID: PMC6615932.

113. Vandewalle G, Archer SN, Wuillaume C, Balteau E, Degueldre C, Luxen A, et al. Effects of light on cognitive brain responses depend on circadian phase and sleep homeostasis. *J Biol Rhythms.* 2011;**26**(3):249-59. doi: 10.1177/0748730411401736. PubMed PMID: 21628552.

114. Chellappa SL, Steiner R, Blattner P, Oelhafen P, Götz T, Cajochen C. Non-visual effects of light on melatonin, alertness and cognitive performance: can blue-enriched light keep us alert? *PLoS One.* 2011;**6**(1):e16429. doi: 10.1371/journal.pone.0016429. PubMed PMID: 21298068. PubMed PMCID: PMC3027693.

115. Dai Q, Uchiyama Y, Lee S, Shimomura Y, Katsuura T. Effect of quantity and intensity of pulsed light on human non-visual physiological responses. *J Physiol Anthropol.* 2017;**36**(1):22. doi: 10.1186/s40101-017-0137-7. PubMed PMID: 28446222. PubMed PMCID: PMC5405487.

116. Thorne H, Hampton S, Morgan L, Skene DJ, Arendt J. Differences in sleep, light, and circadian phase in offshore 18:00-06:00 h and 19:00-07:00 h shift workers. *Chronobiol Int.* 2008;**25**(2):225-35. doi: 10.1080/07420520802106850. PubMed PMID: 18484362.

117. Gumenyuk V, Roth T, Drake CL. Circadian phase, sleepiness, and light exposure assessment in night workers with and without shift work disorder. *Chronobiol Int.* 2012;**29**(7):928-36. doi: 10.3109/07420528.2012.699356. PubMed PMID: 22823876.

118. Grundy A, Sanchez M, Richardson H, Tranmer J, Borugian M, Graham CH, Aronson KJ. Light intensity exposure, sleep duration, physical activity, and biomarkers of melatonin among rotating shift nurses. *Chronobiol Int.* 2009;**26**(7):1443-61. doi: 10.3109/07420520903399987. PubMed PMID: 19916841.

119. Rahman SA, Shapiro CM, Wang F, Ainlay H, Kazmi S, Brown TJ, Casper RF. Effects of filtering visual short wavelengths during nocturnal shiftwork on sleep and performance. *Chronobiol Int.* 2013;**30**(8):951-62. doi: 10.3109/07420528.2013.789894. PubMed PMID: 23834705. PubMed PMCID: PMC3786545.

120. Henriksen TEG, Grønli J, Assmus J, Fasmer OB, Schoeyen H, Leskauskaite I, Bjorke-Bertheussen J, et al. Blue-blocking glasses as additive treatment for mania: Effects on actigraphy-derived sleep parameters. *J Sleep Res.* 2020;**29**(5):e12984. doi: 10.1111/jsr.12984. PubMed PMID: 31967375.

121. Janků K, Šmotek M, Fárková E, Kopřivová J. Block the light and sleep well: Evening blue light filtration as a part of cognitive behavioral therapy for insomnia. *Chronobiol Int.* 2020;**37**(2):248-59. doi: 10.1080/07420528.2019.1692859. PubMed PMID: 31752544.

122. Mortazavi SAR, Tahmasebi S, Parsaei H, Taleie A, Faraz M, Rezaianzadeh A, et al. Machine Learning Models for Predicting Breast Cancer Risk in Women Exposed to Blue Light from Digital Screens. *J Biomed Phys Eng.* 2022;**12**(6):637-644. doi: 10.31661/jbpe.v0i0.2105-1341. PubMed PMID: 36569561. PubMed PMCID: PMC9759638.

123. Mortazavi SAR, Mortazavi SMJ. Women with hereditary breast cancer predispositions should avoid using their smartphones, tablets, and laptops at night. *Iran J Basic Med Sci.* 2018;**21**(2):112-115. doi: 10.22038/IJBMS.2018.27711.6751. PubMed PMID: 29456806. PubMed PMCID: PMC5811748.

124. Arjmandi N, Mortazavi G, Zarei S, Faraz M, Mortazavi SAR. Can Light Emitted from Smartphone Screens and Taking Selfies Cause Premature Aging and Wrinkles? *J Biomed Phys Eng.* 2018;**8**(4):447-452. PubMed PMID: 30568934. PubMed PMCID: PMC6280109.

125. Mortazavi SMJ, Mortazavi SAR, Habibzadeh P, Mortazavi G. Is it Blue Light or Increased Electromagnetic Fields which Affects the Circadian Rhythm in People who Use Smartphones at Night. *Iran J Public Health.* 2016;**45**(3):405-6. PubMed PMID: 27141511. PubMed PMCID: PMC4851763.

126. Taheri M, Darabyan M, Izadbakhsh E, Nouri F, Haghani M, Mortazavi SAR, et al. Exposure to Visible Light Emitted from Smartphones and Tablets Increases the Proliferation of Staphylococcus aureus: Can this be Linked to Acne? *J Biomed Phys Eng.* 2017;**7**(2):163-8. PubMed PMID: 28580338.

PubMed PMCID: PMC5447253.

127. Mortazavi SMJ, Abbasi S, Mortazavi SAR. Regarding: “The Association Between Smartphone Use and Breast Cancer Risk Among Taiwanese Women: A Case-Control Study”. *Cancer Manag Res.* 2020;**12**:12535-6. doi: 10.2147/CMAR.S292761. PubMed PMID: 33324097. PubMed PMCID: PMC7732173.

128. Mortazavi SMJ. Comment on ‘Domestic light at night and breast cancer risk: a prospective analysis of 105 000 UK women in the Generations Study’. *Br J Cancer.* 2018;**118**(11):1536. doi: 10.1038/s41416-018-0060-7. PubMed PMID: 29769746. PubMed PMCID: PMC5988714.

129. Mortazavi SMJ. Re: Insomnia and Mild Cognitive Impairment. *Gerontol Geriatr Med*. 2018;**4**:1-2. doi: 10.1177/2333721418787840. PubMed PMID: 30046649. PubMed PMCID: PMC6055093.

130. Mortazavi SMJ, Dehghani Nazhvani A, Paknahad M. Synergistic Effect of Radiofrequency Electromagnetic Fields of Dental Light Cure Devices and Mobile Phones Accelerates the Microleakage of Amalgam Restorations: An in vitro Study. *J Biomed Phys Eng*. 2019;**9**(2):227-32. doi: 10.31661/jbpe.v9i2Apr.596. PubMed PMID: 31214528. PubMed PMCID: PMC6538905.

131. Shih YW, Hung CS, Huang CC, Chou KR, Niu SF, Chan S, Tsai HT. The Association Between Smartphone Use and Breast Cancer Risk Among Taiwanese Women: A Case-Control Study. *Cancer Manag Res*. 2020;**12**:10799-807. doi: 10.2147/CMAR.S267415. PubMed PMID: 33149685. PubMed PMCID: PMC7605549.

132. James P, Bertrand KA, Hart JE, Schernhammer ES, Tamimi RM, Laden F. Outdoor Light at Night and Breast Cancer Incidence in the Nurses’ Health Study II. *Environ Health Perspect*. 2017;**125**(8):087010. doi: 10.1289/EHP935. PubMed PMID: 28886600. PubMed PMCID: PMC5783660.

133. Lai KY, Sarkar C, Ni MY, Cheung LWT, Gallacher J, Webster C. Exposure to light at night (LAN) and risk of breast cancer: A systematic review and meta-analysis. *Sci Total Environ.* 2021;**762**:143159. doi: 10.1016/j.scitotenv.2020.143159. PubMed PMID: 33131852.

134. Al-Naggar RA, Anil Sh. Artificial Light at Night and Cancer: Global Study. *Asian Pac J Cancer Prev.* 2016;**17**(10):4661-4. doi: 10.22034/apjcp.2016.17.10.4661. PubMed PMID: 27892680. PubMed PMCID: PMC5454613.