REVIEW ARTICLE

The Relationship between Lighting and Physiological Changes in Work Environments: A Systematic Review

Ashkan Jafari Malekabad[1], MSc; Somayeh Bolghanabadi[1], MSc; Raziyeh Janizadeh[1], MSc; Sareh Kowsar[2], MSc; Zahra Zamanian[3], PhD

[1]Student Research Committee, Department of Occupational Health and Safety Engineering, Faculty of Health, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Student Research Committee, Department of Occupational Health and Safety Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran
[3]Department of Occupational Health and Safety Engineering, Faculty of Health, Shiraz University of Medical Sciences, Shiraz, Iran

Correspondence:
Zahra Zamanian, PhD;
Department of Occupational Health and Safety Engineering, Faculty of Health, Razi Blvd, Postal code: 71536-75541, Shiraz, Iran
Email: zamanianz@sums.ac.ir
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Abstract

Background: Vision is one of the most important human senses, and appropriate lighting is one of the most crucial physical factors in various settings, especially in work environments. Poor lighting in the workplace has negative effects on workers' health, productivity, and job performance. Lighting significantly influences many non-visual functions, including physiological and psychological mechanisms and biological-cognitive processes such as circadian rhythm, alertness, core body temperature, hormone secretion, and sleep. Non-visual effects of light on the human body include changes in heart rate, pulse, blood pressure, and the secretion of hormones such as melatonin and cortisol. Therefore, this study aimed to investigate the relationship between lighting and physiological parameters of individuals in work environments.
Methods: In this systematic review, articles published up to December 2023 in the PubMed, Web of Science, and Scopus databases were searched.
Results: The key findings of these studies indicate that the most significant effect of light and illumination is on melatonin secretion. Light with a lower color temperature suppressed melatonin secretion to a lesser extent, whereas light containing blue spectrum components suppressed melatonin secretion more intensely. Heart rate, pulse, and blood pressure also increased in low light intensity and yellow-colored light.
Conclusion: Light and illumination, as a physical factor in the workplace, can affect employees' physiological performance in various ways, impacting health, safety, and work-related accidents. Utilizing these studies, appropriate strategies and achievements can be proposed to improve lighting and maintain workers' health in work environments.

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Background

Vision is one of the most important human senses, and appropriate lighting is one of the most crucial physical factors in various places, especially in work environments.[1, 2] Clear and suitable vision depends on proper and optimal lighting.[3] In the modern era, it is inconceivable to imagine environments (especially work environments) without lighting as humans heavily rely on light for all kinds of activities and enhanced productivity.[4]

Light is a part of the electromagnetic spectrum with wavelengths ranging from 380 to 770 nanometers. When it encounters the photoreceptor cells in the human retina, it is received and then sent to the brain, where its quantity and quality are perceived. The spectrum received from the surrounding environment is interpreted by the brain as light, color, or object based on its characteristics. The optical region of the electromagnetic spectrum includes the infrared, visible, and ultraviolet spectra, and inappropriate lighting can affect various parameters of the workforce.[5]

Numerous studies have shown that physical factors (such as noise, lighting, vibration, heat, cold, and radiation) in the work environment can influence fatigue, mental and emotional state, motivation, and productivity.[6, 7] Workplace lighting, depending on whether it is adequate or inadequate, can have positive or negative effects on human health and productivity.[8]

Poor lighting in the workplace negatively impacts workers' health, productivity, and job performance. Studies have shown that improving workplace lighting can enhance individual efficiency by 3%.[9] Poor lighting may also result in inaccurate perception of environmental information, increasing the likelihood of human error.[3, 10] Providing optimal lighting ensures the optimal functioning of the human visual system, enhancing employee safety, health, and well-being, and significantly reducing human errors, accident rates, and employee absenteeism. Overall, adequate lighting boosts productivity.[11]

Inadequate lighting (either excessive or insufficient) in any environment can lead to various discomforts and even accidents.[1, 12] Exposure to excessive light can cause headaches, fatigue, stress, eye irritation, and anxiety. Insufficient light can lead to eye strain, headaches, dizziness, fatigue, musculoskeletal disorders due to poor posture, and additional bodily strain for visual adjustment.[3, 13] Work environments with poor lighting conditions often experience higher rates of accidents and occupational illnesses due to the visual and non-visual effects of light on various physiological variables, such as the sleep-wake cycle and cognitive functions.[14] Visual effects of lighting include visual comfort and quality, while non-visual outcomes include changes in physiological parameters, cognitive performance, and sleep quality.[15]

The direct effects of light on the human nervous system are related to immediate changes in physiological arousal, while phase-shifting effects pertain to temporal changes in the circadian rhythm.[16] In addition to physiological effects, studies have shown that exposure to higher light levels can lead to increased alertness, perception, and better performance.[17]

In recent decades, various studies have demonstrated that different lighting conditions significantly impact many non-visual functions, including physiological and psychological mechanisms and biological-cognitive processes such as circadian rhythm, alertness, core body temperature, hormone secretion, and sleep.[18] It has also been established that light has non-visual effects on the human body, such as changes in heart rate and blood pressure. Heart rate and blood pressure are associated with the autonomic nervous system and can indicate stress levels.[19] Thus, lighting is a powerful regulator of the circadian system, aligning the human body with the environment. Physiological variables affected by lighting include heart rate, blood pressure, and the secretion of cortisol and melatonin.[18] For example, physiological parameters can be affected by the type of light, color of light, color temperature, and intensity of light and lead to suppression or secretion of melatonin and cortisol hormones, as well as an increase or decrease in the heart rate, pulse, and blood pressure.[20, 21]

A study carried out by Hawes showed that exposure to higher light levels at night led to lower melatonin secretion, increased physiological arousal, higher levels of mental alertness, and improved attention and cognitive performance.[22] Zamanian's study indicated that the impact of bright light on the melatonin and cortisol cycle in night-shift workers increased the plasma cortisol levels with higher light intensity at night.[23] Another study by Chellappa demonstrated that exposure to 6500 Kelvin color temperature fluorescent lamps suppressed melatonin and significantly reduced sleepiness. Additionally, exposure to blue-enriched light increased mental comfort.[14] Tang's study found that the heart rate and visual comfort were likely affected by full-spectrum light, with higher-intensity light correlating with a lower average heart rate and greater visual comfort.[24] Also, Jing's study on miners showed that lighting had a significant negative correlation with the heart rate, electrodermal activity, and respiration. Heart rate was notably affected by lighting, changing significantly from the normal level (200 lx) at 50 lx, while respiration rate and electrodermal activity changed significantly at 10 lx.[25] Gubin's study showed that lighting as an intervening factor could affect systolic and diastolic blood pressure, heart rate, pulse, blood pressure, and melatonin secretion.[26]

Given the claims and previous studies about the non-visual effects of light and lighting on health, especially in work environments, and their relationship with job scheduling, and due to the lack of a comprehensive review on the impact of lighting on important physiological parameters of workers (including the relationship between lighting and changes in the heart rate, blood pressure, and secretion of melatonin and cortisol), this study aimed to investigate the relationship between lighting and physiological changes in individuals in work environments through a structured review.

Methods

Search Strategy

The review was done according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses – PRISMA.[27] This review was conducted by systematically searching for articles published in PubMed, Scopus, and Web of Science in December 2023. The following search strategy (Title and Abstract, while in Web of Science searching in Topic) was implemented in all databases: “Blood Sugar”, “Heart Rate”, “Lighting”, “Illumination”, “Cortisol”, “Melatonin”, “Workplace”, and “Blood Pressure”. Among all the articles related to the review topic, only original research articles evaluating the lighting and physiological parameters of individuals in work environments were included in the systematic review.

Selection Criteria

Only cross-sectional articles examining the relationship between lighting and physiological parameters of individuals in work environments were included in the study. The authors participated independently in the three stages of review (screening, eligibility, and inclusion). In the first stage, titles and abstracts of articles obtained from the search were screened by the authors based on the inclusion criteria. Secondly, they obtained and reviewed the full texts of relevant titles or those with ambiguous relevance. Any disagreements between the authors were resolved through discussion. Finally, studies meeting the inclusion criteria were selected for the systematic review.

To assess the quality of the articles, the authors completed the quality assessment checklist provided by The Joanna Briggs Institute (JBI) for all the studies included in the review. JBI offers a variety of appraisal tools, including questionnaires, to evaluate the validity and applicability of research studies. These questionnaires typically consist of structured questions and criteria designed to assess different aspects of a study, such as its design, methodology, data collection methods, and reporting quality. The specific questionnaire used is determined by the type of study being evaluated. For example, JBI provides distinct appraisal tools for various study designs, including analytical cross-sectional studies, qualitative research, quasi-experimental studies, and more. Each tool is tailored to the specific features and requirements of the study type.[28]

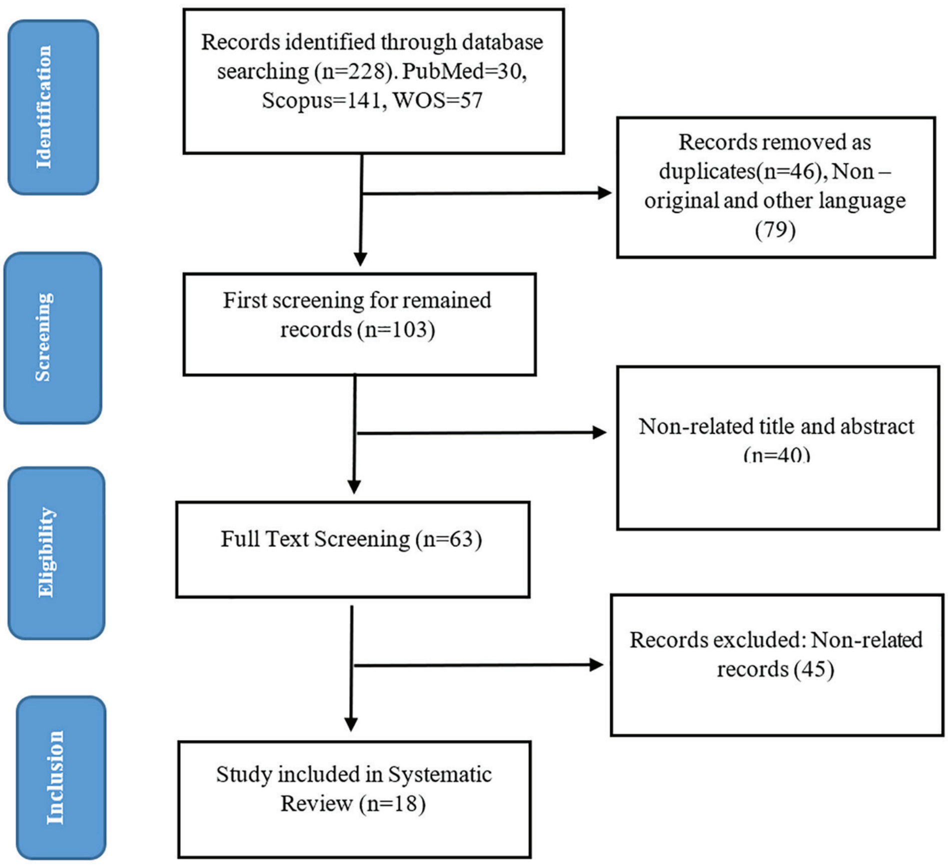

Figure 1: Flowchart of the included studies in a systematic review

Eligibility Criteria

The search results were reviewed and selected based on the following criteria:

- Original cross-sectional studies
- Studies published in English
- The study population consisting of workers in work environments
- The outcomes reporting the effects of lighting on physiological parameters of employees (such as heart rate, blood pressure, etc.)

The authors extracted the study information, including the year, objective, method, main results, and limitations of the studies that met the eligibility criteria.

Study ID: 25381

Results

A total of 228 studies were identified through a systematic search in the three electronic databases (Figure 1). After applying filters for original studies and the English language, the total number of studies was reduced to 149. After removing duplicates (n=46), studies that did not align with the study title (n=63) and those that did not meet the inclusion criteria based on the abstract and full-text review, 18 studies finally remained; after quality assessment, all of them were included in the systematic review. The characteristics and information of the included studies are shown in Table 1.

These studies were conducted on various groups in work environments (including industrial, academic, and office settings). In most of these studies, different groups were exposed to light with varying intensities and colors. The impact of different lighting conditions on individuals' physiological parameters was then assessed through urine, saliva, and blood sampling, as well as measuring oral and core body temperature.

Discussion

One of the significant environmental factors in the workplace that can affect individuals' physiological parameters is lighting. Research has shown that the level of ambient light can have extensive effects on the hormone levels, heart rate, blood pressure, stress and anxiety levels, sleep patterns, and individuals' hormonal cycles. This study examines the relationship between workplace lighting and individuals' physiological parameters to gain a better understanding of this connection and its impacts on health and well-being. Most studies in this field indicate a correlation between workplace lighting and individuals' physiological parameters.

Overall, the results of studies suggest that changes in workplace lighting can affect the individuals' physiological parameters in various ways. These changes include alterations in the level and color temperature of lighting and its impact on melatonin levels, cortisol levels, heart rate and pulse, blood pressure, and the risk of breast cancer.

Changes in Melatonin Levels

Several studies have examined the effects of light on melatonin levels in the human body. These studies indicate that light can influence the secretion process of melatonin, which is a crucial hormone in regulating the body's biological clock. Different types of light have varying effects on melatonin levels. Generally, the most significant impact of light and lighting on physiological parameters is on melatonin levels and the disruption of its natural balance.[29-32, 35, 36, 38, 40, 42, 43, 46, 47] Additionally, light can affect the quality and amount of sleep, which can lead to sleep disorders and decreased melatonin secretion, thereby causing issues for individuals working at night shifts.[30, 31, 42] It has also been shown that changes in plasma melatonin levels can effectively influence several physiological factors, such as core body temperature, sleep health, and psychiatric disorders like depression.[43] Regarding the impact of light and lighting on melatonin, all studies confirmed that light affected melatonin levels, and reduced melatonin levels were considered a significant factor in causing adverse effects. Light wavelengths in the range of 446-477 nanometers had the greatest impact on melatonin suppression.[35]

The Impact of Light Color, Temperature, and Features on Physiological Parameters

Various studies have shown that different characteristics of light can have diverse effects on individuals' physiological parameters. Using light with appropriate and controlled features and color temperature can enhance the alignment between the body's biological clock and work-rest patterns, improving sleep quality and work performance.[34-38, 40, 44, 47]

It was found that narrow-band blue LED light, particularly wavelengths from 446 to 477 nanometers, has a greater impact on suppressing melatonin compared to 4000K white fluorescent light. Generally, lighting conditions that include blue components reduce melatonin secretion and increase cortisol secretion.[35, 36, 40, 47] Additionally, using a yellow lamp without blue components can minimize melatonin suppression caused by light exposure (yellow light increases melatonin secretion).[36] The color yellow was found to have a greater impact on increasing heart rate and blood pressure (reducing diastolic blood pressure and increasing systolic blood pressure) compared to green and dark blue.[44] The color temperature of light also affects physiological parameters, with lower temperatures causing less melatonin suppression.[38, 40, 47]

Table 1: characteristics of included articles

Row	Title	Year	Aim	Method	Main outcome	Quality of study (score out of 20)	Limitations
1	An evaluation of scheduled bright light and darkness on rotating shiftworkers: Trial and limitations[29]	1995	Evaluating the Effectiveness of a Program of Bright and Dark Scheduled Light to Shift the Circadian Pacemakers of Rotating Shift Workers	Thirteen workers were exposed to bright light of 6000-12000 lux and ambient light of 1200-1500 lux during at least half of their 12-hour night shifts for 3 months. Urine samples were taken to analyze melatonin and its metabolite 6-hydroxy melatonin sulfate(a urinary metabolite of melatonin).	Morning melatonin suppression on night shifts has resulted in significant circadian changes in 50% of workers. Changes in urinary melatonin levels are the first tangible evidence that light technology can alter workers' circadian rhythms in an industrial environment.	17	Over different periods, workers have been exposed to bright lights, and information regarding their actual experiences may have been biased. Response bias may have occurred because some workers may have been influenced by seminars and training discussions.
2	Night shift work, light at night, and risk of breast cancer[30]	2001	Investigating the Relationship Between Nighttime Light Exposure and Increased Breast Cancer Risk (Due to Suppression of Natural Melatonin Production and Increased Estrogen Secretion) in Women	Data collection occurred from April 1993 to December 1995, using face-to-face interviews to gather information on known or suspected breast cancer risk factors. Questions covered job history, sleep patterns, habits from 10 years before diagnosis (or reference date), and bedroom light characteristics.	An increased risk of breast cancer was observed in individuals whose nighttime melatonin levels were at their highest (indicating lack of sleep). Additionally, the risk of breast cancer increased in individuals who reported working night shifts for at least some duration in the 10 years leading up to breast cancer diagnosis. Individuals with the brightest bedrooms also showed signs of increased risk.	18	It cannot be accurately stated that all factors affecting breast cancer have been fully and correctly considered.
3	Working under daylight intensity lamp: An occupational risk for developing circadian rhythm sleep disorder? [31]	2005	Treating Chronic Fatigue and Depression with Melatonin in a 47-Year-Old Individual Complaining of Severe Fatigue and Daytime Sleepiness with an Irregular Sleep-Wake Pattern Over the Past 20 Years	A 36-hour sampling of melatonin level and oral temperature was performed (12 samples, once every 3 hours). To restore the circadian rhythmicity and stabilize his sleeping and waking pattern, a combined treatment including melatonin consumption at night along with morning light therapy (09:00 hours) (800 lux for 1 hour) plus avoiding strong light at night was performed.	Exposure to intense light as part of a work environment may have a serious impact on the organization of endogenous circadian rhythms and should be considered a workplace hazard for complaints of sleep disturbances and sleep disorders (reduced melatonin secretion).	17	The exclusion of all influential parameters.
4	Circadian disruption and breast cancer from melatonin to clock genes[32]	2005	Supporting the Potential Role of "Circadian Disruption," Especially from an Environment with Altered Light (Such as Nighttime Light)	Examining circadian rhythm	Reduced melatonin may increase the risk of breast cancer through various mechanisms including increased estrogen production and altered estrogen receptor function.	17	A large prospective study, with blood and morning urine samples, can also advance this field.

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5	Shift work, light at night, and breast cancer on Long Island, New York[33]	2006	Investigating the Relationship Between Breast Cancer and Shift Work	In this study, 576 women with breast cancer from August 1996 to June 1997 were examined to investigate the relationship between night light history (15 and 5 years prior) and the duration of evening and night shift work in their occupations. Participants were divided into three groups based on the number of years worked with one or more evening shifts per week, and the association between the duration of evening and night shift work and breast cancer was examined.	This study does not support shift work as a factor in increasing breast cancer risk. Breast cancer had no association with overall shift work (OR = 1.04, 95% confidence interval (CI): 0.79, 1.38) or afternoon shifts (OR = 1.08, 95% CI: 0.81, 1.44). Additionally, overall and afternoon shift work were not significant factors, and analysis of night shift workers resulted in a reduced risk estimate.	18	To clarify existing contradictions in findings, future studies should focus on strengthening shift work estimates, using innovative methods to assess nighttime light exposure at home, conducting precise and appropriate measurements regarding melatonin hormone, and investigating genetic polymorphisms that may interact with environmental light on breast cancer risk.
6	Effects of the physical work environment on physiological measures of stress[34]	2010	Examining the Effects of the Physical Work Environment on Both Physiological Measures and Stress Responses	The study involved 60 workers in various work environments to examine changes in heart rate variability (HRV) and cortisol levels. Government employees participated in both traditional and modern work environments. They carried electronic devices for 24 hours and used saliva tubes to collect cortisol throughout the day.	Results showed that HRV is associated with a second-degree pattern, with the highest values at midnight and decreased during working hours. Working in an old office space reduced HRV at night and increased morning cortisol levels further. This study demonstrated that physical characteristics of the workplace can influence physiological responses and endocrine glands, which are not associated with health factors such as smoking, physical fitness, alcohol or caffeine consumption. Individuals working in older environments, facing less air and light quality, had lower HRV at night and higher cortisol levels.	18	The exclusion of all individual factors.
7	Blue light from light-emitting diodes elicits a dose-dependent suppression of melatonin in humans[35]	2011	Investigating Circadian Rhythm Disruption and Sleep Deprivation as Risk Factors for Astronauts, NASA Ground Control Staff, and Civilians	In the current study, blood samples were collected before and after exposure to light to determine melatonin levels. Additional UV measurements and light radiation along the central axis were performed. Participants spent different nights in the laboratory, and blood samples were taken at specified times. The melatonin content of plasma samples was determined using the original RIA method developed by Rollag and Niswender.	Results showed that blue LED light may have a stronger melatonin suppression effect compared to white fluorescent light at 4000k, which is commonly used in general lighting fixtures. Research also indicated that the short-wavelength part of the light spectrum, especially wavelengths of 446 to 477 nanometers (blue color), is more effective for melatonin suppression, and monochromatic blue light may be more effective for increasing human alertness.	17	The limitation of this study is that eight individuals were only exposed to white fluorescent light at 4000 Kelvin in one radiation compared to blue LED illumination across a full spectrum of low to high intensities.

Row	Title	Year	Aim	Method	Main outcome	Quality of study (score out of 20)	Limitations
8	Out of the Lab and into the Bathroom: Evening Short-Term Exposure to Conventional Light Suppresses Melatonin and Increases Alertness Perception[36]	2013	Studying the Impact of Evening Light Emitted by Household and Workplace Lamps in a Natural Environment on Melatonin Levels and Alertness in Humans	In this study, healthy individuals (6 men, 3 women, aged 22 to 33) were exposed to low constant light (less than 10 lx) for six evenings from 7:00 PM. Additionally, they were exposed for 30 minutes late in the evening (2 to 6 PM) and 1 hour before bedtime to light emitted by 5 different lamps. Measurement of melatonin levels in individuals' saliva was conducted using lamps simulating lighting conditions in bathrooms, office environments, and industrial/sports settings. Saliva samples were collected during and after light exposure at specified time intervals, and melatonin concentration was determined using commercial equipment.	Using a yellow lamp without blue components can minimize the melatonin-suppressive effect caused by exposure to light (yellow light increases melatonin secretion). Conversely, lighting conditions containing blue components significantly reduced melatonin secretion (office daylight white, bathroom daylight, warm white Planon, room daylight).	17	The limitation of this study is the number of participants and the diversity of low light.
9	physiological strain in the Hungarian mining industry: the impact of physical and psychological factors[37]	2016	Identifying Physiological Stress in Workers Using Work Pulse and Examining the Effects of Work-Related Psychological Factors	In this study, 71 miners in 5 mining factories were examined. A Bio port Recorder was used to collect physiological data. Physiological data were measured using a multi-channel recorder at the workplace, with six separate channels used to record heart rate and core temperature. The focus of this report was primarily on heart rate results.	In this study, the light level in the workplace increased from 15-20 lux to approximately double, ranging from 36 to 45 lux. Results showed that higher light levels led to a significant decrease in physiological stress during work and also reduced heart rate and pulse by 5 to 18 percent.	18	The participants did not participate in clinical laboratory workplace measurements. Also, fundamental influencing factors such as age, and lifestyle (blood pressure, smoking, body mass) were not analyzed.
10	Effect of color temperature on melatonin production for illumination of working environment[38]	2017	Evaluating the Effects of 7 Multi-Colored White Lights with a Continuous Range of Color Temperatures (CCT) from 1600 Kelvin to 14000 Kelvin at a Constant Illumination Level of 200 lx on Visual Performance and Melatonin Synthesis	Two experiments were conducted in this study involving 17 students (8 men and 9 women, aged 20-27). The first experiment focused on visual performance, and the second on melatonin production. Five types of fluorescent lamps with continuous color temperature (CCT) from 1600 Kelvin to 14000 Kelvin at a constant illumination level of 200 lx were used. Additionally, melatonin levels were measured in saliva samples from 16 students.	Multi-colored white light with a temperature below 2000 Kelvin disrupted color perception. Melatonin suppression was minimal at temperatures below 2000 Kelvin, but with an increase in color temperature, the level of melatonin suppression increased. CCTs of around 3000 Kelvin are likely suitable for environments that need to maintain circadian rhythms. Additionally, using CCTs of at least 4000 Kelvin can enhance compatibility with nighttime work.	18	The exclusion of other lighting sources

Row	Title	Year	Aim	Method	Main outcome	Quality of study (score out of 20)	Limitations
11	The effect of blue-enriched white light on cognitive performances and sleepiness of night-shift workers: A field study[39]	2017	Investigating Whether Blue-Enriched White Light is a Practical Strategy for Reducing Sleepiness and Improving Cognitive Performance During Night Shifts	Intervention before and after was conducted on 30 petrochemical industry workers. Each participant was exposed to two new lighting conditions (K 17000 and K 6500, enriched white light with blue) for one week each. Melatonin levels were assessed by collecting saliva samples and using the ELISA method. Saliva samples were collected at four different time points during the night shift (7 PM, 11 PM, 3 AM, and 7 AM) using a saliva sampler (Sartsert, Germany).	Compared to normal lighting conditions, it was observed that sleepiness and melatonin rhythm significantly decreased in participants exposed to blue-enriched white light, indicating a significant effect of lighting conditions on salivary melatonin rhythm. Also, white light enriched with a color temperature of 17000 K had greater effects on melatonin suppression than 6500 K light.	17	Participants, despite the difficulties of this trial, did not have a positive attitude towards it. Using their reported perceptions of wakefulness may lead to biased measurements.
12	Applying Melanopic Lux to Measure Biological Light Effects on Melatonin Suppression and Subjective Sleepiness[40]	2017	Demonstrating the Validity of Melanopic Lux in Humans Using a Semi-Natural Environment	This research aimed to investigate the effects of different lighting conditions on melatonin suppression and mental drowsiness in 30 individuals (men and women) aged 18 to 35. Saliva samples were collected from these individuals under 19 different lighting conditions for 30 minutes in the evening and one hour before bedtime, and then their melatonin concentration and mental drowsiness were measured. The illuminance level ranged from 3 to 604 lux in each lighting condition.	Being exposed to high-blue light level conditions (CCTs from 4200 to 12000 K) significantly reduced melatonin concentration compared to low-light control conditions. Over time, significant changes in melatonin concentration were observed for three lighting conditions: “Uplight,” “Downlight,” and low-light control.	18	It should have been evaluated in natural conditions and environments.
13	The cumulative effects of work-related factors increase the heart rate of cabin field machine operators[41]	2018	Determining Which Work-Related Factors Increase the Risk of Cardiovascular Disease in Machine Operators	One of the variables of interest was the lighting inside the cabin. The response variable was workload heart rate (HRWORK), which was paired with relevant environmental measurement data over time. The resting heart rate (HR REST) of the operators was also recorded. These measurements were taken after the end of shifts and during rest periods when the operators were at rest.	The average brightness inside the cabin was 2658 lux. The average HRWORK of CTL machine operators was 91 BPM, while their HRREST was 66 BPM. The average heart rate of operators during the day varied from 90 BPM at the beginning of the shift to 100 BPM at the end of the shift. The physical conditions of the operators’ work environment caused significant stress, leading to increased heart rate at the end of the day and increased risk of cardiovascular diseases. Results indicated that the increase in heart rate at the beginning of the shift may be associated with insufficient sleep and rest for the operators. Cabin lighting was identified as the most influential factor in the work environment.	17	The exclusion of all effective factors.

Row	Title	Year	Aim	Method	Main outcome	Quality of study (score out of 20)	Limitations
14	Comparison of melatonin profile and alertness of firefighters with different work schedules[42]	2018	Comparing Salivary Melatonin and Sleepiness on the Last Night Before Transitioning to a Day Shift at 19:00, 23:00, 3:00, and 7:00 Among Petrochemical Firefighters (PFFs) Working Seven and Four Consecutive Night Shifts	Eighty firefighters in a petrochemical company were evenly distributed into two regular shift systems comprising 7-night shifts, 7-day shifts, and 7 off-duty days (7 N7D7O) and 4 N4D4O. Four saliva samples were taken from each participant at four-hour intervals, and participants were also asked to record their mental assessments of drowsiness every four hours. During the night shift, samples were collected every four hours at 7:00 PM, 11:00 PM, 3:00 AM, 5:00 AM, and 7:00 AM using a saliva collection device (Sartsert, Germany). Illuminance was measured from 0 to 100000 lux.	The melatonin level in the third and fourth measurements, and the overall change in melatonin, statistically differed between the two different shifts ($p<0.05$). Furthermore, the overall trend of melatonin changes after light and caffeine control between the two shifts was statistically significant ($p<0.001$). The maximum level of melatonin was detected in individuals working in the 7 N7D7O shift pattern at the end of the work shift, while the maximum level of melatonin measured in the 4 N4D4O shift pattern was observed around 3:00 PM.	16	Melatonin was only measured during night shifts, and the melatonin level was not evaluated in both groups on a complete day. This study was limited to only one-night shift in the entire work cycle.
15	Effect of radiance-dimmer devices simulating natural sunlight rhythm on the plasma melatonin levels and anxiety and depression scores of the submarine personnel[43]	2019	Assessing the Impact of Dim Light Adjustment on Naval Submarine Personnel of the Islamic Republic of Iran Army Using Radiant Devices Based on Natural Solar Light Changes Over the Day. Also, This Study Aims to Investigate the Effect of Sunlight Simulation by Artificial Radiating Devices on Serological and Psychological Measures of Submarine Personnel	In this non-randomized controlled trial, participants were randomly assigned to two experimental and control groups. Each group consisted of 26 participants, all of whom were male and aged between 21 and 29 years. Both groups resided in an underground submarine room with a constant brightness intensity covering an area of 120 square meters. The experimental group was provided with additional lighting devices that adjusted the intensity of radiation according to the natural day-night cycles of sunlight. Plasma melatonin levels and depression and anxiety scores were determined before and after the experiment for both groups. Two types of light (sunlight lamps and moonlight lamps) with radiation intensities (200 lux sunlight and 200 moonlight) were used.	Adding artificial lighting devices to natural day-night cycles with standard illumination in the same environments significantly reduces plasma melatonin levels in submarine personnel and decreases anxiety levels noticeably. Furthermore, altering plasma melatonin levels can effectively impact several physiological factors such as core body temperature, sleep health and disorders, and psychiatric disorders like depression. In the control group, however, melatonin levels and psychological measures not only did not decrease during the study process but increased significantly.	16	Some of them are as follows: measuring job status, mission duration, personality traits, or other factors such as family was not feasible. Also, demonstrating effectiveness over a full year and determining the impact of different seasons was not feasible. Other limitations were the small number of participants and a history of past sleep disturbances.

Row	Title	Year	Aim	Method	Main outcome	Quality of study (score out of 20)	Limitations
16	increasing workers comfort: experiment of the effect of color and lighting in assembly manufacture[44]	2021	Measuring and Determining the Impact of Color and Light at Specific Wavelengths on Illumination Levels and Physical Comfort of Employees	The method used in the study involved conducting an experiment designed in the manufacturing industry. The experiment stages included: configuring color and light in the employees' work environment, measuring the amount of brightness in the configuration, and measuring the physical status of employees at work, including heart rate, blood pressure, and pupil changes. The color configuration uses dark blue, green, and yellow. Analysis was conducted in the morning, afternoon, evening, and night. Color and light effects in the cable assembly production room of the automotive electrical installations are produced.	Yellow color can increase heart rate by up to 4.85 percent, while green color can decrease diastolic by 2.95 percent and systolic by 1.29 percent. The effect of green color on heart rate, blood pressure, and pupil size reduces the physical comfort of the workers. Yellow color has an average heart rate of 92.84 bpm. Green color has an average bpm of 86.52. Dark blue color has an average bpm of 87.91. This study demonstrates that human physical comfort, especially employee heart rate, depends on the effect of the yellow color, increasing it by up to 4.85 percent. In comparison, the green color reduced employee heart rate by 0.97 percent. The effect of yellow and light on employees' blood pressure is that it reduces diastolic blood pressure by 2.92 percent and increases systolic blood pressure by 0.68 percent. In comparison, green color reduced diastolic blood pressure by 2.95 percent and systolic blood pressure by 1.29 percent.	17	The exclusion of all individual factors.
17	Lighting for work: a study on the effect of underground low-light environment on miners' physiology[45]	2022	Examining the Impact of the Lighting Environment in a Coal Mine on Human Physiology	The study aimed to investigate the effect of different light levels (0 lx, 10 lx, 50 lx, 100 lx, and 200 lx) on three indicators: heart rate, electrodermal activity, and respiration. This experiment selected 18 male graduate and undergraduate students aged between 22 and 30. Their majors are mining and safety-related, so they are all familiar with the underground coal mine environment. The test times were between 8:00 AM to 11:00 AM and 2:00 PM to 5:00 PM. Each experiment lasted for 55 minutes, so 6 subjects could be tested in one day. 18 subjects were tested over 3 days for one light level and 15 days for five light levels. In this study, a simulation lighting system for an underground coal mine was constructed.	Lighting has a significant negative correlation with heart rate, electrodermal activity, and respiration. It appears that heart rate is significantly influenced by lighting and changes significantly from the natural level of 200 lx to 50 lx. In contrast, respiration rate and electrodermal activity change significantly at 10 lx. Results indicate that coal mine lighting should be around 50 to 100 lx. At lx 0, lx 10, and lx 50, all physiological indices are higher than the normal level. The lower the light level, the greater the difference between the experimental group and the normal level. When lighting is 50-100 lx, the indicators are close to the normal level. At lx 10, heart rate, electrodermal activity, and respiration rate are significantly different from the natural level. One-way ANOVA and box plot analysis show that heart rate changes significantly at 50 lx or less, while respiration rate and electrodermal activity are not as sensitive as heart rate. They change significantly at 10 lx or less.	17	The exclusion of other occupational groups working in the mine.

Row	Title	Year	Aim	Method	Main outcome	Quality of study (score out of 20)	Limitations
18	A 24-hour lighting scheme to promote alertness and circadian entrainment in railroad dispatchers on rotating shifts: A field study[46]	2022	Determining Whether Exposure to Effective Circadian Lighting (a Combination of Blue and White Light (6500 K) in the Morning and Ineffective Circadian Lighting (a Combination of Red and White Light (4000 K)) in the Afternoon and Evening. Circadian Alignment Affects Physiological Parameters and Objective and Subjective Measures	This study was conducted at the Seyrantepe control center. Sixteen railway workers (all male with an average age of 37.3 years (SD 6.4)) participated in the baseline data collection phase. Due to operational considerations of this center, only 10 participants (average age 36.7 years (SD 6.2)) could participate in the intervention phase of the study. Baseline data was collected in October 2015 and intervention data in February 2019. Participants were exposed to two lighting conditions: existing facility lighting in the baseline phase (October 2015) and experimental lighting during the intervention phase (February 2019). This intervention utilized a dynamic LED lighting system consisting of adjustable direct/indirect white pendant lights (either K 6500 or K 4000) placed above participants' workstations and complemented with recessed lights with asymmetric blue-saturated lights (λpeak = 460 nanometers) for morning (07:00-12:00) to enhance circadian alignment, and saturated red lights (λpeak = 630 nanometers) during afternoon tonight (12:00-07:00) to enhance alertness. For the combined blue + white (6500 K) intervention, the average EH was 240 lx (SD 60.0) and the average EV was 85 lx (SD 35.0). For the combined red + white (4000 K) intervention, the average EH was 400 lx (SD 90.0) and the average EV was 110 lx (SD).	This field study demonstrates that lighting interventions (red and blue light combined with white light) can be effective in improving circadian alignment, delaying melatonin onset in low light, reducing objective and subjective sleep disturbances, and improving sleep quality, especially in work environments. This intervention provides better coordination between light exposure and darkness in day shifts and rest patterns but does not significantly increase melatonin onset time. Also, reduced mental sleepiness was observed only when participants were off duty during daytime shifts.	18	The exclusion of all individual and environmental factors.

lux: unit of light intensity; OR: odds ratio; CI: confidence interval; HRV: heart rate variability; LED: light-emitting diode; K: Kelvin (unit of color temperature); CCT: correlated color temperature; HRWORK: workload heart rate; HR REST: resting heart rate; BPM: beats per minute; SD: standard deviation; EH: horizontal illuminance; EV: vertical illuminance; λpeak: peak wavelength

Melatonin suppression was negligible at color temperatures below 2000 Kelvin, and using CCTs of at least 4000 Kelvin could improve adaptation to night work.[38] Additionally, white light enriched with a color temperature of 17000 Kelvin had a greater effect on melatonin suppression compared to light with a color temperature of 6500 Kelvin,[47] and blue light levels with CCTs from 4200 Kelvin to 12000 Kelvin had significant effects on melatonin suppression.[40]

Light intensity is another important feature that can affect physiological parameters.[37, 43, 45] Increasing the light level in the workplace from 15-20 lux to nearly double, between 36 and 45 lux, significantly reduces physiological stress during work.[37] Generally, at lower lighting levels, physiological indicators are higher than normal.[37, 45] Additionally, adding artificial lighting devices to natural day-night cycles significantly reduced plasma melatonin levels and anxiety in submarine personnel.[43]

Changes in Cortisol Levels

Cortisol, another hormone, is affected by lighting. Generally, the secretion of melatonin and cortisol are inversely related; hence, the opposite effects discussed in section 4-1 apply to cortisol secretion, where reduced melatonin secretion leads to increased cortisol secretion.[29-32, 34-36, 38, 40, 42, 43, 46, 47] Monochromatic blue light, by suppressing melatonin and increasing cortisol, enhances alertness and reduces drowsines[35]. Working in old office spaces with lower air and light quality leads to increased morning cortisol levels.[34]

Changes in Light Levels and Variations in the Heart Rate, Pulse, and Blood Pressure

The physical conditions of the workplace cause significant stress on operators. Studies have shown that light and illumination as physical environmental factors can affect the heart rate, pulse, and blood pressure of worker.[34, 37, 41, 45] Results indicated that increasing light levels reduced physiological indices such as the heart rate and puls.[37, 41, 45] Working in old office environments was found to decrease the heart rate variability (HRV) at night.[34] Increased light levels significantly reduce physiological stress during work and relatively reduce the heart rate and pulse by 5 to 18 percent.[37] At light intensities of 50-100 lux, all physiological indices are at normal levels, while at intensities below 50 lux, physiological indices including heart rate are above normal levels.[45] Additionally, the physical conditions in the cabins of CTL machine operators led to an increased heart rate at the end of the day and an increased risk of cardiovascular diseases.[41] The impact of light colors in the workplace on the heart rate and blood pressure showed that yellow light could increase the heart rate (4.85 percent) and systolic blood pressure (0.68 percent) while decreasing diastolic blood pressure (2.92 percent). In contrast, green light can reduce diastolic blood pressure by 2.95 percent, systolic blood pressure by 1.29 percent, and employee heart rate by 0.97 percent.[44]

Changes in Light Levels and Increased Breast Cancer Risk

One of the potential adverse effects of light exposure is an increased risk of breast cancer. Studies have shown that breast cancer can occur through reduced melatonin secretion and increased estrogen production.[30, 32] These studies reported an increased risk of breast cancer in individuals who worked at night shifts and had the brightest bedrooms in the ten years leading up to their diagnosi.[30] However, another study did not consider shift work a risk factor for breast cancer, finding no correlation between breast cancer and general or evening shift work, contrary to the other two studies.[33]

The studies reviewed emphasize the significant influence of workplace lighting on employees' physiological responses and circadian rhythms. Exposure to blue-enriched light and high color temperatures (such as 4000K or higher) leads to suppressing melatonin , disrupting circadian rhythms, impairing sleep quality, and potentially increasing the risk of conditions such as breast cancer and cardiovascular diseases. In contrast, lighting with lower color temperatures (below 2000K), such as yellow light, has been shown to promote circadian rhythm stability and reduce physiological stress. Moreover, poorly lit work environments, particularly in older settings, are associated with elevated cortisol levels and decreased heart rate variability, which contribute to increased stress. Based on these findings, adjusting lighting intensity to a range of 50-100 lux and incorporating multi-colored lighting systems could help improve the sleep quality, reduce circadian misalignment, and enhance overall employee productivity. These insights underscore the importance of optimizing workplace lighting as a strategy to improve the employees' health and performance.

Conclusion

The relationship between lighting and physiological parameters in the workplace is an important and practical subject that requires more precise attention and examination. Light and illumination, as physical environmental factors, can affect employees' physiological performance in various ways, impacting health, safety, and work-related incidents. The significance of non-visual light indices and their effects on human health are often overlooked in lighting standards. These indices include melatonin secretion, circadian rhythms, alertness, and hormone secretion, which extensively impact physiological and psychological health, particularly through the reduction of melatonin and the increase of estrogen. This indicates the need to enhance lighting standards to include non-visual light indices to significantly improve individuals' health and well-being. Utilizing controlled color temperature lighting features, such as reducing color temperature to mitigate the negative effects of blue light and adjusting light intensity during different work hours, can help improve these indicators. Using the results of these studies, it is possible to propose appropriate achievements and strategies to improve lighting and maintain the health of employees in the workplace, taking into account the requirements of the job and task, by making changes in the existing lighting system and reducing the physiological effects related to light and lighting.

One of the limitations of this study is that it is restricted to studies published in English, which may introduce language bias and limit the generalizability of the results to studies published in other languages. Additionally, most of the existing research has focused on the short-term effects of workplace lighting exposure, while the long-term effects, particularly in night shifts and shift work conditions, have not been adequately explored. Therefore, it is recommended that future studies place greater emphasis on investigating the long-term effects of lighting in shift work and night work environments to evaluate these factors more comprehensively in such settings.

Authors' Contribution

Ashkan Jafari Malekabad: Conceptualization, database search, screening of articles, data extraction, drafting of the manuscript. Somayeh Bolghanabadi: Database search, quality assessment of included studies, data extraction, writing and editing the manuscript. Raziyeh Janizadeh: Article screening, data extraction, preparing tables and figures, reviewing and editing the manuscript. Sareh Kowsar: Methodology, quality appraisal using JBI tools, supporting data interpretation, manuscript revision. Zahra Zamanian: Supervision, project administration, resolving disagreements in study selection, final critical revision of the manuscript, and approval of the final version.

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Conflict of Interest

The authors declare no competing interests.

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