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The Effect of the Circadian Lighting on the Productivity Level: An Experiment in a Co-Working Space

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Abstract Exposure to natural features, such as natural light, directly correlates with high rates of the individual's productivity level. An artificial lighting technique that mimics natural light in its aspects like intensity and dynamic color ranges is called Circadian Lighting, which significantly impacts the individual's productivity level. This paper aims to examine the effect of Circadian Light on the productivity level of the users of a co-working space. It is hypothesized that using Circadian Light in a working environment will enhance the circadian rhythm of individuals by improving their sleeping and waking cycles, and this enhancement will directly correlate with a high level of productivity for individuals in such an indoor working environment. This research experiment is hosted in a co-working space, which is considered a semi-stressful working environment. The research type is experimental design research. By applying a self-reported questionnaire about productivity changes, the methodology is formed to conduct answers about the effect of the Circadian Light on the changes in circadian patterns, especially the sleeping and waking cycles, and its relationship with productivity levels. The overall sample size is thirty-three participants. The reversal design technique 'ABAB' was applied to ensure productivity and circadian rhythm enhancements from the questionnaire answers. The results show statistical data using Excel charts and graphs and outputs using SPSS. The results indicate an improvement in the productivity of the individuals, good sleeping qualities, and alertness in the early morning; all aspects of changes can be mentioned due to the changes in the melatonin levels. The paper's conclusion supports and approves the hypothesis. This paper also concludes the importance of dynamic lighting techniques in interior architectural design. The significance of this paper is in filling the gap in the research of adding Circadian Lighting to a semi-stressful working environment such as co-working spaces.

Keywords Circadian Rhythm, Sleeping-Wake Cycle, Productivity, Co-Working Spaces, Circadian Lighting

1. Introduction

Sleeping and working hours shape two-thirds of individuals' daily lives. A significant amount of research has highlighted that a productive lifestyle for youth, young adults, and elderly adults should consist of an average of eight hours per day of sleeping [1] and seven to eight hours per day of working [2]. The sleeping and wake cycle directly affects the productivity rate during working hours.

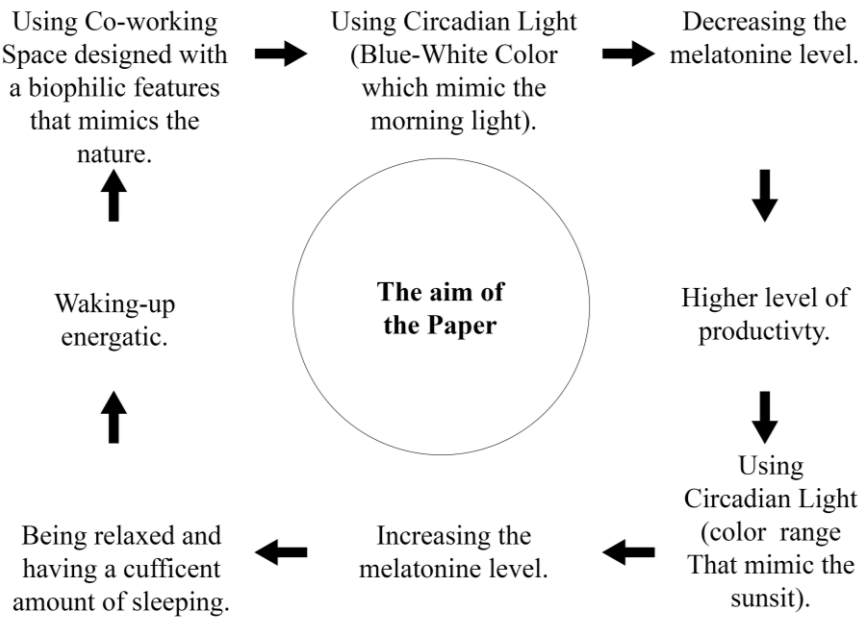

Figure 1. Represent the cycle that the paper is aiming to analyze

One of the most effective keys to enhancing the circadian rhythm of individuals is exposure to natural lighting, especially during the first minutes of the morning [3]. Indoor working environments could negatively affect this exposure to natural light, so providing an artificial tool that substitutes this lack is necessary for increasing productivity rates. Circadian Light is an artificial lighting system or technique miming natural light in its colors, temperature, and intensity [4]. So, following the aspects that lead to good sleep quality through exposure to the light of the individuals will enhance their circadian rhythms and improve their overall experience throughout the day [5].

After reviewing previous literature, it was shown that many studies were applied to highlight the importance of Circadian Light for productivity by enhancing individuals' sleep-wake cycle and circadian rhythm. Other studies uncovered the importance of transferring from the regular meaning of working environments to the new trends of working environments, especially co-working spaces. Circadian light needs to be used in these semi-stressful working spaces. This paper aims to merge the meaning of using Circadian light in co-working spaces, which represents an ideal working environment that leads to an increment in the productivity level of individuals and the circadian rhythm in general (Figure 1).

2. Artificial Lighting in Working Environments and Users' Productivity Level

It was previously confirmed that exposure to nature enhances the user's productivity. Nevertheless, to better explore such a phenomenon, it is essential first to explore what defines a productivity level and what factors in nature individuals could best benefit from to enhance their productivity level.

2.1. Productivity Level

Productivity is a phrase that describes how effective and efficient a person is at completing a task by comparing the number of outputs or outcomes with the inputs, including time, human, and physical resources [6]. Productivity (P) is defined as output (O) / input (I). This approach to productivity measurement works well for gauging the output of employees over whom you have no influence. It may also be used to assess the productivity levels of both individuals and groups [7]. This method of measuring productivity could generally mimic one of the tests that evaluate how quickly a person can solve complex problems that indicate an enhancement in productivity, called Raven's Progressive Matrices [8].

To enhance this productivity level, it was previously confirmed that exposure to nature enhances users' productivity [9]. Unfortunately, the indoor environment plays an indispensable part in individuals' day. In the indoor environment, artificial lighting was shown to primarily affect the physiology and psychology of individuals, especially by disturbing the individuals' circadian rhythm [10]. Accordingly, the present study will explore the definition and factors in the surrounding physical environment (in terms of lighting) that can promote a better circadian rhythm.

2.2. Circadian Rhythm

The circadian rhythm, thought to be a twenty-four-hour cycle, is primarily responsible for regulating each person's biological clock and is necessary to coordinate all bodily

processes and functions, including feeling alert, sleeping, hungry, and controlling body temperature. One of the most significant circadian rhythms in the body is the sleeping-waking cycle, which is in sync with the day-night cycle [10]. From a biological perspective, the circadian rhythm is governed by the hypothalamus, a brain region that houses the suprachiasmatic nucleus (SCN), which regulates all bodily cycles. Signals that regulate body activity at different times of the day are delivered by clock genes located in the SCN [10].

Environmental cues, particularly exposure to light, directly regulate the biological clock. A well-synchronized circadian rhythm will support the body's biological processes that guarantee a healthy lifestyle. For instance, it aids in the production of proteins by the digestive system to enable regular mealtimes and aids other bodily glands to encourage the body to waste energy [10]. Light is a significant external cue that influences the messages the SCN delivers to the body to coordinate circadian cycles because the SCN is extremely sensitive to light. Day and nighttime cycles are closely linked to circadian rhythms. Light has the most significant impact on circadian rhythms. However, other cues like exercise, social engagement, and temperature can also affect the internal clock [10]. When people are exposed to natural light during the day, their internal clock is triggered, resulting in signals that help them stay awake and attentive. The internal clock causes the production of melatonin, a hormone that encourages sleep when darkness descends, which aids in our ability to fall asleep and stay asleep throughout the night. Thus, circadian rhythms create a regular cycle of restorative sleep that allows for greater levels of activity during the day by synchronizing awake and sleep with day and night [11].

According to the study applied by Scheuermaier, Laffan, and Duffy [12], young adults are not exposed to light like elderly adults, which leads to a problem related to the circadian rhythm, which indicates the need for young adults to compensate for their need to be exposed to natural light during their daily activities. The study suggests that higher light exposure in older adults may contribute to the age-related phase advance of the circadian rhythm and influence their sleep patterns. A similar survey by V. Gabel et al. [13] also shows the need for young adults to be exposed to light.

The role of natural light in enhancing the circadian rhythm and reaching the natural light is crucial. This is most likely because light impacts the hypothalamus in the brain, which regulates the body's internal clock and the production of melatonin and serotonin. A higher level of creativity is also associated with natural light. Natural light is the primary source of vitamin D. Thus, those who do not receive enough sunshine may develop a deficiency of this vitamin. Problems with teeth, muscles, and bones can result from low vitamin D levels, which can have a domino impact on other areas of health [9]. Different theories, science fields, and design methods have discussed this effect of natural light. For example, Visual Ergonomics theory discusses the importance of natural light by examining the relationship between lighting and visual comfort while considering variables such as illuminance, color temperature, glare, and flicker. A study by C. F. Reinhart, J. Mardaljevic, and Z. Rogers [14] examined the relationship between natural light and workers' performance. A science field called Neuroscience indicates the importance of natural light and the human biological cycles, attitudes, and thought processes, all of which can influence productivity [15], as it mainly focuses on analyzing how experiences can cause the brain to change in both anatomy and function and provides details on how environmental variables and interventions can be used to enhance cognitive abilities and brain activity.

Given that working hours are widely seen as a significant portion of the day for young people and adults, and the circadian rhythm governs sleep, getting a good night's sleep is positively correlated with practical workdays. When it comes to working hours, seven to eight hours a day is deemed productive for both adults and young adults [16] [17]. It was also highlighted that visual and brain fatigue caused by prolonged computer use can severely impair the cognitive functions of users, reducing the worker’s productivity level. People who do not get enough natural light in their lives are more likely to notice a decrease in their mood and their productivity levels [9]. Accordingly, a growing amount of research has highlighted the role of some types of artificial lighting that copy the same motion, colors, and temperature as natural light, including the Circadian Light. Therefore, the following sections will explore how Circadian Light works and the benefits it could bring to the indoor working environment.

2.3. Circadian Light

The previous sections of this paper indicated the physical, biological, and psychological effects of natural light in terms of increasing the productivity level of individuals, as also mentioned by Brandt [18]. The lack of natural light in indoor spaces or the insufficient amount of it must be replaced with an artificial one that mimics the same motion, colors, and temperature as the natural one. The benefit of the dynamic motion of the light is that it could enhance the parasympathetic and sympathetic nervous systems and increase mental activity when it goes to the blue-white spectrum, and it makes people feel sleepier in lower color temperature lighting [19]. The type of lighting applying these aspects and effects is called Circadian Light [20].

Circadian Light is a wellness melanotic-illuminance type of lighting used in indoor spaces in addition to other ambient and task lamps (low-melanotic-illuminance) in the space to enhance the well-being aspects of the individuals [21]. Brown [22] examines the effects of light on human circadian rhythms, focusing on the function of intrinsically photosensitive retinal ganglion cells (ipRGCs). The results show that melanopic illuminance stimulates these cells, regularly anticipating non-visual reactions such as

melatonin suppression and circadian phase resetting. As the research shows, melanopic illuminance is a dependable parameter that may be used to inform lighting designs that support human health in various settings.

Circadian Light's importance is easier to understand than the regular types of artificial lighting systems. Generally, the artificial lighting system had standards that could offer working satisfaction; the color temperature range between 4000K and 4500K yields a bright white light suitable for lighting an entire room. Brilliant bluish-white light produced at 5000K and above is ideal for commercial situations; this lighting temperature is equal to an illuminance of 200 to 500 lux, which is suitable for offices with different types of tasks [19]. The entire body of the individuals has different circadian rhythms due to their exposure to the natural light in the morning; for this instance, this meaning in the static artificial lighting scenarios could lead to eye strain, which in turn can lead to headaches and other visual issues; this may lead the individuals to experience lethargy and demotivation, which reduces productivity in the workplace [19]. Biologically, the brain and nervous system are significantly impacted by dynamic circadian illumination. For instance, it has been demonstrated that exposure to blue light increases the synthesis of serotonin, a neurotransmitter that controls mood, hunger, and sleep. On the other hand, it has been demonstrated that exposure to red light stimulates the production of melatonin, a hormone that controls sleep-wake cycles [4]. As mentioned by M. G. Figueiro, M. Kalsher, B. C. Steverson, J. Heerwagen, K. Kampschroer, and M. S. Rea [4], self-reported sleepiness scores on the Circadian Light intervention days were significantly lower than usual. As expected, participants reported feeling significantly more awake, alive and energized on the intervention days than on the baseline.

Hence, this study's goal is to experiment with the effect of Circadian Lighting on the productivity level of users in a working environment.

2.4. Types of Working Environment

Exploring the different working environments is essential to determine their effect on productivity levels. Outdoor working environments are considered to be productive working environments; an increase in mood, attentiveness, and reduced stress can be achieved through exposure to natural light and materials; outdoor work environments allow employees to participate in physical activity, which has been linked to improved cognitive function [23]. However, there are also advantages to indoor working environments for employees. For example, the controlled indoor temperature reduces the risk of discomfort and interruption from adverse weather. Creating calmer and less distracting environments is also feasible to improve focus and attention span. Indoor environments can also enhance employee well-being and job satisfaction by offering greater privacy and security [24].

Indoor working environments could be classified into regular working environments like offices, remote working environments like working from home, and a third new trend is flexible working environments like co-working spaces. This study highlights the adverse effects of regular and remote working environments and shows the importance of flexible ones. In regular working environments like offices, lack of privacy might make it difficult for users to block distractions and concentrate on their work [25]. Regular types of work environments can be particularly challenging for people who work in creative or cognitively demanding fields since they could feel constrained by company policies or the expectations of others [26]. Users may experience physical discomfort in regular workplace environments, such as headaches, eye strain, and back pain. These bodily effects may exacerbate users' mental stress and impair their ability to focus on tasks [27]. On the other hand, it might be challenging for remote workers to draw a distinct boundary between work and break time. This might cause people to struggle to turn off work-related duties, resulting in overwork, burnout, and lower productivity [28].

Co-working spaces are communal workspaces where individuals from different industries or professions gather to work in an adaptable and cooperative environment. Numerous services and facilities are available at these places, such as Wi-Fi, coffee makers, workstations, chairs, and conference spaces. Co-working space mainly consists of shared spaces and office spaces. The concept of co-working spaces first emerged in the mid-2000s. The idea is credited to Brad Neuberg, who established the first co-working space in San Francisco in 2005 and coined "co-working" to describe his concept of a shared workplace in a neighborhood. Since then, coworking spaces have proliferated across the globe, catering to startups, independent contractors, and small businesses at thousands [29].

3. Method

3.1. Case Study

3.1.1. Criteria of Selection

To examine the impact of circadian lighting, which replicates natural light and boosts productivity, an indoor coworking space with a "biophilic design" is needed. Biophilic design, influenced by nature, will lend credibility to the experiment by demonstrating that no elements of the physical space could potentially interfere with users' ability to be productive.

As per the literature review, exposure to natural light can improve an individual's sleeping-wake schedule, and variations in melatonin levels have the potential to alter an individual's circadian rhythm within a day. Therefore, the

reversal design technique (A-B-A-B) will be used in this study to compare the effects of Circadian Light on an individual's circadian rhythm and behavior. This is because the A-B-A-B design is most appropriate when an intervention is expected to alter the degree or rate of target behavior [30]. The technique will demonstrate the causality of the effect of the Circadian Light on productivity. It will ensure internal validity by duplicating the psychological changes' results, which will guide the experiment to the time frame for each participant (a 4-day experiment with a day of baseline questionnaire) [30]. Thus, a baseline questionnaire will be used for each putrescence in the experiment (BS), followed by a questionnaire to assess the impact of changes in productivity after day one of being exposed to the Circadian Light (A), a repetition of the questionnaire after a second day to assess the withdrawal effect on the productivity and the previous effect of the Circadian Light on the sleeping quality (B); the third day is the second day for being exposed to the Circadian Light, which is the validation of the effect the lighting system on the productivity level, which will be clear on the answers of the questionnaire (A); at the last day there will be no exposure to the Circadian Light, but the changes in the circadian rhythm are needed to be determined (B). According to this order, the selected co-working space must have clients with long-term conditions to stabilize the questionnaire distribution (five days or more rental conditions).

3.1.2. The Selected Case Study

The main objective of the case study selection is to match the main requirements highlighted in (Table 1). The selected case study is in Heliopolis, Cairo, Egypt. It has eight rooms, two restrooms, storage, and an external entrance. It is situated on the ground level. The rooms are all around the same size, measuring three meters in width and three and a half meters in length. The rooms have similar furnishings, artificial lighting, wall cladding, flooring, and plantations. All rooms contain wooden disks in the same condition as ambient light and task light, wooden cladding, light marble flooring, and natural plantations such as pots. However, four rooms have windows, while the other has artificial ventilation. All eight room users are marketing professionals in various specialties; they use laptops and digital displays for work, and each room's stakeholders have a multi-month rental agreement. In May 2024, when the experiment started, the co-working space had thirty-five participants and clients; all were welcome to join the experiment. Due to the absence of two participants in the middle of the experiment, only 33 out of the 35 were considered in this study, 19 males and 14 females. The plan and images of the room of the selected case study are clarified in (Figure 2).

3.2. The Selected Circadian Light

As Circadian Light is a wellness lighting product, the critical role in selecting it for the experiment is the effect of the spectrum activating the melanotic system and how it affects the wake-up cycle. The chosen product, known by its commercial name, Sky View 2 "SV2", offers a spectrum that can reach 6600K and lumens with 1200lm. Figure 3 shows the wavelengths provided by the SV2 creators. This wavelength mimics the wavelength of the visible sunlight [32]. The main reason for selecting SV2 is that the lighting system must be portable so as not to conflict with the design of the co-working space and its policies. The system must also be controlled remotely for the privacy of the clients. All this is offered in SV2.

Table 1. The main criteria for the case study selection

	Primary Criteria for the Case Study Selection.
1.	A co-working space that contains private office rooms and other shared spaces (semi-stressful working environment).
2.	Designed with a biophilic design so as not to conflict with the effect of the nature of the Circadian Light.
3.	Clients that have a long-term rental condition.
4.	Have the capacity to accommodate the number of participants that will be in the sample size (Minimum = 30 participants) [31].
5.	All rooms are almost equal in their features to ensure no other factor will affect the treatment.
6.	Participants from young adults as a majority.

Figure 2. Plan the selected co-working space and distribute the Circadian Light in each room (distance max 1.5 meters from each disk)

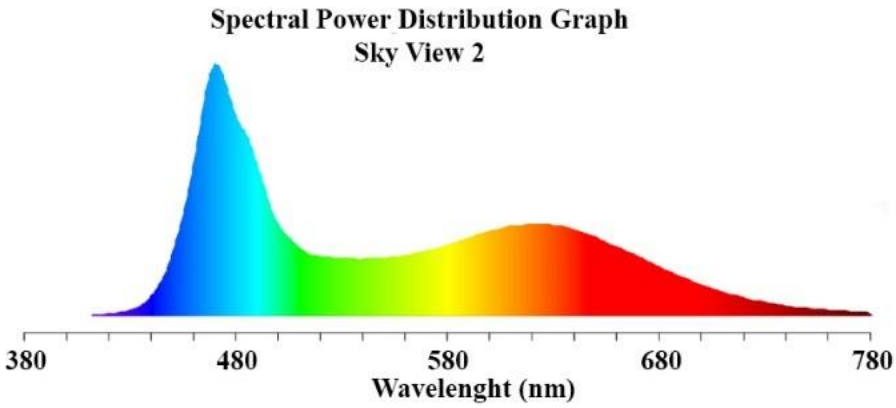

Figure 3. Wavelength for SV2

SV2 is intended to replicate the changes in solar radiation in a manner that aligns with circadian rhythms. By mimicking the impacts of variations in natural light, such as color temperature and intensity, which are directly related to user productivity, SV2 can positively affect users' circadian cycles. One unique feature of the product is its capacity to synchronize light with the body's circadian cycles. This was compared to the science of circadian rhythm after examining an experiment using a comparable product from the same manufacturer. Using a mobile Wi-Fi network, the SV2 application automatically adjusts its time zone to replicate natural lighting conditions. The research author selected the Saturday to Thursday workdays in the application configuration to align with the co-working space's regulations and the aims of the experiment. Based on the average user sleep cycle, the author selected an 8:00 am wake-up time and a 10:00 pm sleep time. According to the SV2 manufacturer set-up installations, the lighting feature should be positioned in the participant disks in the center of the room, 1 to 2 meters away from each stakeholder. The production firm recommends this arrangement, and comparable trials have been conducted. Every day, from 10 a.m. to 6 p.m., the participants were exposed to the SV 2 lighting system for eight hours. Questionnaires were distributed using Google Forms to find the general needed data at 6 pm.

4. Results

The questionnaires were categorized into three categories of questions to conduct three main groups of results. The first is the demographic aspects of the participants, starting with their gender and age groups, whether their work nature requires exposure to portable device screens, their location inside their rooms, the number of working hours, and whether their rooms contain windows or not. All these aspects are fixed through the five days of the experiment, so it will be analyzed in descriptive analysis to understand their effectiveness in the two other categories of results. The second category discusses the changes in the productivity level of the participants after exposure to Circadian Light, whether it is a psychological enhancement in the productivity level or a physical enhancement by increasing the ratio of finishing the tasks per day. The last category will discuss the changes in the circadian rhythm by understanding the changes in sleep quality and the overall energy, mood, and alertness in the day after exposure to light.

The results were collected from the participants' answers and analyzed and visualized using SPSS and Microsoft Excel. The Descriptive analysis was applied mainly to determine the nominal questions' mean, mode, frequency, and percentages. For the Inferential analysis, the One-Way ANOVA test and the Post Hoch Scheffe test were used to analyze the significance of the treatments.

4.1. Demographic Aspects

The analysis of the demographic aspects shows that the percentage of the average age group is 21.1% and 42.4% for the age group categories 18-24 and 25-34, respectively (Table 2). This indicates that the participants are mainly youth and young adults. The sample consists of 57.6% Males and 42.4% Females, which indicates the sample almost equal in terms of gender; 100% of them were exposed to portable device screens in the five days of the experiment to accomplish their work tasks, and all of them were stuck to their disks inside the rooms. The participants marked their daily working hours, and it shows that on the first day (μ= 4.15), it is above 7 hours; on the second day (μ=4.27), it is above 7 hours; on the third day (μ=4.48), it is above 7 hours; on the fourth day (μ=4.48), it is above 7 hours; and finally, on the last and fifth day (μ=4.51), again it is above 7 hours. 14 out of the 33 participants' disks are in rooms with windows, and the other 19 are not. All the results are shown in Table 2.

Table 2. The table shows the demographic aspects of the participants

Category	**Age Group**			**Gender**		**Exposure to portable devices**		**Window Exitance**		**Working Hours Per Day**	
Group	18-24	25-34	35-44	Male	Female	Yes	No	Yes	No	**Day**	Mean
Frequency	7	14	12	19	14	33	zero	14	19	**1**	μ= 4.15
Percent	21.2%	42.4%	36.4%	57.6%	42.4%	100%	0%	42.4%	57.6%	**2**	μ=4.27
										3	μ=4.48
Cumulative Percent	21.2%	63.6%	100%	57.6%	100%	100%	100%	42.4%	100%	**4**	μ=4.48
										5	μ=4.51

4.2. Productivity Changes

Two questions have been asked about the lighting system; the first is to assess the lighting system, and the second asks to which extent you think the lighting system is related to enhancing your productivity level in achieving your work tasks. As mentioned before, all questions were repeated over five days; the target of these questions was first to detect the effect of the Circadian Light and second to determine whether or not the existence of the natural light would affect the treatment. By analyzing the means of the samples about satisfaction with the lighting system in their rooms, they show that they are above the natural level of satisfaction (above μ=2.00) and show a higher satisfaction on the days of exposure to the Circadian Light (Day 2 and 4) (Table 3).

Applying the Post Hock Scheffe test for tracking the changes in the productivity level in the five days of the experiment showed a high significance on days 2 and 4 compared with days 1,3 and 5 (p-value= 0.000 for both days) (Table 4). To determine whether this significance is affected by the existence of the windows in 4 rooms out of 8, an independent t-test was applied to determine the effect; the results show a significance for the windows' existence on days 3 and 5, which indicates that the effect the Circadian Light will be better with the existence of an amount of the natural light (Table 5).

4.2.1. Psychological Enhancements

Four questions were asked to examine the impact of Circadian Lighting on the psychological aspects of the participants in terms of increasing their productivity. The first question asks about the focus, the second question asks about the productivity rate in comparison with the regular productivity rates, and the third one asks if the participants had noticed any difference in the speed of accomplishing the tasks, and finally, the fourth question asks about the overall satisfaction of the productivity rate. The results show a significant effect for the Circadian Light on the days of exposure (days 2 and 4), which indicates that the treatment affects psychological matter (Table 6). All answers to these four questions were analyzed using the Post Hock Scheffe test.

4.2.2. Physical Enhancements

Three main questions were asked to determine if there is a physical improvement in the productivity level needed to accomplish the tasks. The first question asked if there was any particular pressure in achieving the task and if this could be considered an outer factor that could interrupt the effect of the Circadian Light; the second and third questions are correlated together as they are asking about the number of tasks received per day and the number of tasks accomplished, so through using excel another column had been generated to calculate the productivity rates (Productivity rate= The number of tasks accomplished/ Number of tasks received). By comparing the means of the answers to the question asking about stress with the mean of the question (μ=1.50) (the answers are No-Yes), the results show that all the participants are above the mean in the five days, which indicates no pressure through the days of the experiment, which indicates pressure will not affect the result. By applying the Post Hock Scheffe test, the result shows that the productivity rate had been enhanced in the days of the exposure in comparison with day 1, as the significance showed as follows: Day1-2: (p-value= 0.000), Day1-3: (p-value= 0.035), Day1-4: (p-value= 0.000), and Day1-5: (p-value= 0.000). This also indicates that the effect of the Circadian Light continued on the third and fifth days without being exposed to the light (lower significance on day three than on day 5) (Table 7).

Table 3. The mean comparison for the rating of the lighting system in the 5 days of the experiment

Statistics					
Day	**Lighting System Rating 1**	**Lighting System Rating 2**	**Lighting System Rating 3**	**Lighting System Rating 4**	**Lighting System Rating 5**
Mean	2.273	2.909	2.091	2.939	2.455

Table 4. The significance of the lighting system in the productivity level in the five days of the experiment.

Effect of the lighting system offered in the five days on the productivity level (Significance in gray).																				
Day	1				2				3				4				5			
	2	3	4	5	1	3	4	5	1	2	4	5	1	2	3	5	1	2	3	4
Sig.	.000	.311	.000	.905	.000	.000	.998	.000	.311	.000	.000	.844	.000	.998	.000	.000	.905	.000	.844	.000
*. The mean difference is significant at the 0.05 level.																				

Table 5. An Independent T-test was performed to determine the effect of the window's existence

To what extent does the lighting system positively affect your ability to complete work today?					
Day	1	2	3	4	5
Sig.	0.233	0.375	0.027	0.269	0.007

Table 6. The table shows the effect of Circadian Light on the psychological enhancement of productivity

Question	Focus	The productivity rate in comparison with the regular productivity rates	Noticing any difference in the speed of accomplishing the tasks	Overall satisfaction
Sig.	.000	.000	.000	.000

Table 7. The Physical Productivity Rates

Effect of the lighting system offered in the five days on the Physical Productivity Rate (High Significance in Dark Gray- Lower Significance in Light Gray).																				
Day	1				2				3				4				5			
	2	3	4	5	1	3	4	5	1	2	4	5	1	2	3	5	1	2	3	4
Sig.	.000	.035	.000	.000	.000	.000	1.000	.997	.035	.000	.000	.001	.000	1.000	.000	.990	.990	.997	.001	.000
*. The mean difference is significant at the 0.05 level.																				

4.3. Sleeping-Wake Cycle Changes

4.3.1. Sleeping

To determine the changes in the circadian rhythm, changes in sleeping quality are crucial if they are related to melatonin levels. Participants answered that they did not face an external factor that interrupted their sleeping time during the five days of the experiment. (Figure 4) shows an increase in the number of sleeping hours starting from day three and continuing on day 4, indicating that the Circadian Light's effect still exists and reaches its maximum on day 5. The participants' sleeping mood is shown in the following percentages: Day 1: 0% Energetic, 15% Relaxed, 52% Neutral, and 33% Tired. Day 2: 12% Energetic, 12% Relaxed, 55% Neutral, and 21% Tired. Day 3: 3% Energetic, 70% Relaxed, 27% Neutral, and 0% Tired. Day 4: 12% Energetic, 27% Relaxed, 58% Neutral, and 3% Tired. Day 5: 3% Energetic, 67% Relaxed, 30% Neutral, and 21% Tired. The results of the mood match with the results of the number of sleeping hours, as in days 3 and 5, an increase in the relaxation level had been shown; this indicated melatonin secretion. By comparing the means for the question asking about the ability to fall asleep quickly, μ=2.00 is regular any day, above is fast, and lower is slow; the results show that the means in the five days are as follows: Day 1 (μ= 1.97), Day 2 (μ= 2.18), Day 3 (μ= 2.67), Day 4 (μ= 2.45), and Day 5 (μ=2.61). It shows that the mean increased on days 3 and 5.

4.3.2. Waking up

After three days of gradual enhancement in the sleeping quality due to the melatonin secretion caused by the exposure to the Circadian Light, the overall energy level and alertness were calculated from the participants' answers. By using the Post Hock Scheffe test, the results of the answers show that the participants rated themselves with a high level of energy in the morning on Days 1 and 2, which could indicate that an outer effect caused the results in the comparison between day 1 and days 3 and 5, and a higher level of energy had been shown, as the significance between day 1 and 3 (p-value= 0.000) and between day1 and day 5 is (p-value= 0.000); the relation between day 1 and four shows a lower significant (p-value= 0.002) (Table 8). On the other hand, the calculation of the alertness level the next day shows similar findings as the results show a significance as follows: day 1 with day 2 (p-value= 0. 925), day 1 with day 3 (p-value= 0. 000), day 1 with day 4 (p-value= 0. 003), and day 1 with day 5 (p-value= 0. 000) (Table 9). The results show changes in the circadian rhythm, leading to an energetic feeling and alertness the next day of exposure to the Circadian Light.

4.4. Results Summary

The results show that the treatment of being exposed to the Circadian Light mainly increased the productivity level psychologically and physically and led to changes in the circadian rhythm, as it enhanced the quality of sleep, which directly correlated with an energetic feeling the next day of exposure and also a high level of alertness to accomplish tasks.

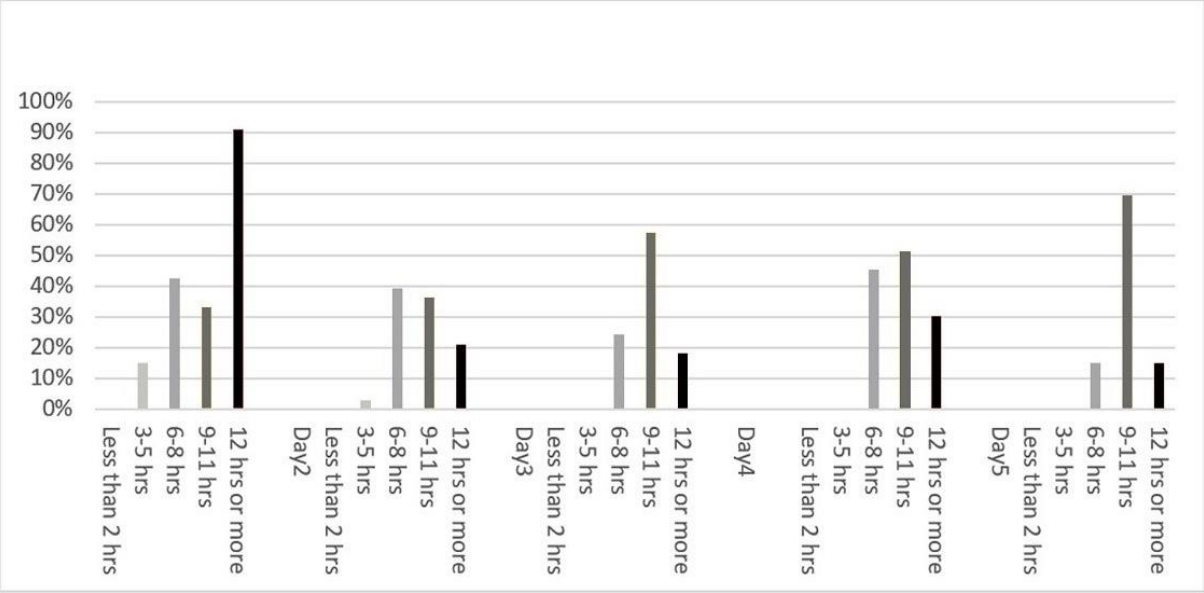

Figure 4. The Graph shows the percentage of sleeping hours in the 5 days of the experiment

Table 8. Energy Levels (High Significance in Dark Gray, Lower Significance in Light Gray)

The level of Energy in the morning of the five days (High Significance in Dark Gray- Lower Significance in Light Gray).																				
Day	1				2				3				4				5			
	2	3	4	5	1	3	4	5	1	2	4	5	1	2	3	5	1	2	3	4
Sig.	.027	.000	.000	.000	.027	.000	.027	.000	.000	.000	.360	.996	.000	.027	.360	.182	.000	.000	.996	.182
*. The mean difference is significant at the 0.05 level.																				

Table 9. Level of Alertness (High Significance in Dark Gray, Lower Significance in Light Gray)

The alertness level in the five days (High Significance in Dark Gray- Lower Significance in Light Gray).																				
Day	1				2				3				4				5			
	2	3	4	5	1	3	4	5	1	2	4	5	1	2	3	5	1	2	3	4
Sig.	.050	.000	.000	.000	.050	.050	.088	.014	.000	.050	1.000	.994	.000	.088	1.000	.972	.000	.014	.994	.972
*. The mean difference is significant at the 0.05 level.																				

5. Discussion and Conclusions

5.1. Discussions

This study aims to analyze the effect of the Circadian Light on the productivity level of the co-working space users, which was applied through the method chapter in this paper. The hypothesis is that circadian light positively affects productivity and circadian rhythm, especially sleeping and weak cycles, due to the enhancement of melatonin secretion levels. Circadian Light is hypothesized to enhance these aspects as it is a type of artificial lighting that mimics the natural light in its color range, dimming [4]. The results were categorized into three sections, and the results approved of the hypothesis.

The demographic analysis of the results shows that the participants consist of 19 males and 14 females; most are youth and young adults. All participants were exposed equally to the different types of lighting, even the lighting of the portable devices, during the five days of the experiment. The results showed that windows have a significant effect when the Circadian Light is added compared with rooms with no windows. This ensures the importance of mixing natural light and artificial Circadian Light.

According to the age groups, the selected age group in this study (youth and young adults) shows a positive correlation in their productivity level with the existence of Circadian Light. The study by Scheuermaier et al. [12] shows that older adults get a higher level of lighting exposure than young adults. The findings of Scheuermaier et al. [12] are similar to the findings of this research, as both contribute to the importance of offering more natural lighting exposure for young adults.

The result also supports the study's hypothesis, which was applied by Figueiro et al. [4]. The result of this paper showed a psychological enhancement that leads to a higher productivity level, which can again ensure the correction of the hypothesis discussed by Jason Brainard, Merit Gobel, Benjamin Scott, Michael Koeppen, and Tobias Eckle [10], who mentioned that light affects the productivity of individuals. G. Abramo and C. A. D'Angelo mentioned that Productivity (P) is defined as follows: output (O) / input (I). By following this method, the paper showed that the productivity level had been physically measured [7].

R. B. Bouncken and A. J. Reuschl mentioned that co-working spaces are productive working environments [29], which controlled the case study selection in this research. The design of the selected co-working space matched the biophilic aspects, which were also hypothesized to increase productivity and enhance individual satisfaction [33].

The results indicate an enhancement in the circadian rhythm, which could be correlated with the hypothesis of Figueiro et al. [4], which suggests that the circadian light enhances the sleeping and waking cycle. The results show an enhancement in sleep quality, especially in the relaxation level before going to bed and its depth, and an increase in sleeping hours. The results also show a higher level of energy in the morning the day after exposure to the Circadian Light and a higher level of alertness. Using the reversal design technique (ABAB) helped to determine these changes and ensure internal validity by duplicating the results of the psychological changes applied through the experiment.

The laboratory studies applied by M. Frontczak and P. Wargocki show results that match those of this paper [22]. Although the two papers use different methods, they agree that controlling the lighting color ranges will directly affect positive enhancements in the individual's alertness level, automatically enhancing the Circadian rhythm.

The results of L. K. Grant et al. [21] also match the results of this paper. Both measure the working productivity and sleeping-waking cycle. The difference was only in the type of working environment, but both confirmed the correctness of the hypothesis.

5.2. Conclusions

This study examines the impact of Circadian Light on co-working space users' productivity, shedding light on an essential aspect of workplace design that significantly enhances employee performance and well-being. The findings of this study demonstrate how crucial it is for Circadian Lighting to align with individuals' biological cycles to optimize productivity. The study found that productivity was much higher when Circadian Light exposure was present than when it wasn't. This supports the hypothesis that Circadian Lighting, which synchronizes with individuals' circadian rhythms, might improve efficiency. The productivity increases over the five days of observation, suggesting that exceptional performance requires ongoing exposure to Circadian Light. This finding is critical to designing work environments that support people's natural cycles and increase their general well-being and productivity.

This research suggests that incorporating Circadian Lighting systems into current workplace design methodologies might result in a happier, more productive, and healthier workforce. The author recommends finding the effect of the different demographic aspects in a similar study with a larger population and also highlights a recommendation for understanding the impact of Circadian Light in the long term.

The limitation of this study could be clearly shown in the sample size, as the author was restricted in finding a co-working space designed with a biophilic design, which limited the freedom of the selection. Most of the participants did not permit the author to use cameras to record their movements throughout the days of the experiment. This study did not analyze whether the participants drank caffeine or exercised during the questionnaire period, which could be considered in further research. These factors could give extra accurate results on the short and long-term effects of the Circadian Light. Tracing the issue and finding a more comprehensive solution are recommended for further research.

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