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Effects of Blue Light on Cognitive Performance

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Abstract- *Many people spend their leisure time in front of computers, laptops, and mobiles which are equipped with LED devices. These devices have a tendency to emit short-wavelength blue light which contains high energy. Exposure to short-wavelength (450-480nm) blue light can cascade number of effects on our cognitive functions. Therefore, effects of blue light on cognitive performance are examined here, by using LED screen and a blue light filter screen cover. During the 5 hour daytime study seven healthy male participants were exposed to two different screen interfaces for three and half hours (3:30) under a controlled environment. Series of cognitive tasks were performed during the study and further analysed by using various methods. Results suggest that there was a significant difference for factor screen, in EEG delta theta activity, mood, sustained attention (reaction time task), short term memory (verbal memory task), and active memory (visual memory task). Continuous exposure to LED screen has led to decrease in frontal region delta theta activity and increased alertness. Whereas exposure to blue light filter screen has elevated dizziness, memory performance and mood. Thus continuous exposure of blue light is bad for mood, circadian rhythm, and memory performance.*

Key Words: Cognitive, Blue Light, Melatonin, Circadian rhythm, alertness.

1. INTRODUCTION

Over the last decade technology has evolved rapidly. There are currently 3.6 billion internet users worldwide, which means about half of the world population is using computers, cellular phones, and laptops on daily basis. Most of these devices are equipped with light emitting diodes (LED). LED devices emits short wavelength [8] high energy blue light (450-495 nm). Blue light controls our circadian rhythm [16] by decreasing and increasing the amount of melatonin in our body. Melatonin [10] increases in the absence of blue light and triggers sleep, whereas presence of blue light keeps us awake. In earlier days when there were no artificial lights, people used to spend their nights in dark. Nowadays, people are surrounded by artificial sources of light. Artificial lights have a tendency to emit short wavelength blue light. Artificial light sources include laptops, mobiles, televisions, tube lights, and bulbs. Everyone interacts with these devices daily and gets exposed to blue light.

Continuous exposure of artificial blue light disturbs our sleep patterns and cognitive performance. Cognitive performance [15, 20] includes memory, mood, attention, sleep-wake cycle, and alertness. Exposure to artificial light could lead to chronic insomnia [12], heart disease [6], and depression [13]. Exposure to short wavelength bright light reduces melatonin levels and improves alertness [7]. Electroencephalography (EEG) low frequency delta –theta activity (1-7 Hz) is also reduced in the presence of artificial blue light [22].

Here, an LED backlit laptop was used to study the effects of blue light on cognitive performance. On the other hand a blue light filters can block some amount of blue light therefore blue light protection filter with retina protection factor 30 (RPF-30) was applied on LED screen so that it could act as another screen interface. Same participants were exposed to LED screen interface and blue light filter interface. During the screen exposure, cognitive tasks were performed by participants to measure sustained attention and memory performance. It was assumed that EEG low frequency delta-theta activity [14, 18, 19] attenuates with continuous exposure of LED backlit screen. EEG and KSS were used as objective and subjective measures to quantify sleepiness. For mood assessment visual analogue mood scale was used. Finally, repeated measure anova was used for statistical analysis.

2. METHODS

2.1 Study Participants

Participants were voluntarily recruited from PEC University of Technology. All seven participants were healthy young male (age range, 23-26 years; mean 24 ± 1 Standard Deviation). Entire study procedure was explained to the participants individually. Visually impaired participants with colour blindness and diminished pupils were excluded from the study. Participants who wear glasses were also included. Smoking, caffeine, alcohol, and drug consumptions were set as exclusion criteria. Participates were advised to avoid these things during the experiment and to follow a regular sleep-wake cycle.
Questions were asked from potential participants about their quality of sleep. To measure quality sleep Pittsburgh sleep quality index (PSQI) was used .PSQI [1] contained 19 self-rating questions and 5 questions by bed partner or roommate. Only self-rating questions were included in scoring. Seven component score of 19 questions were further analysed to a global score (ranging, 0-21; with "no difficulty" to "extreme difficulty"). Participants who scored 0-9 were included in the study. It described sleep behaviour and sleep quality of all the participants.

2.2 Study Protocol

The study was carried out between the months of March and April. A controlled laboratory room was used to block all external lights during the study. Room was setup in such a way that only the light from the laptop should fall onto participant eyes as shown in Fig 1.2. Distance between the chair and laptop was maintained 60 cm's. A video EEG machine was placed adjacent to the chair to record delta-theta activity shown in Fig 1.3. During the entire study participate remained in the seated position. Ambient temperature of the room was set to 21ºC. To maintain low lighting conditions all the lights were turned off. HP laptop (P077tx; series LED backlit screen) with diagonal length 15.6 inches was used as a user interface as shown in Fig 1.1. On the other hand for second screen interface, Eyesafe blue light filter with RPF-30 was applied on the HP laptop as Eyesafe claims that RPF-30 blocks about 30% of blue light.

The entire study was composed of two parts. Firstly, seven participants were called one by one each day to perform some series of tasks on LED screen interface. After the first part of study was done same participants were recalled to perform same tasks on blue light filter interface (filter was attached to LED screen). Study duration was set to 5 hours which included EEG electrode placement and dark adaptation followed by three and half hours (3:30 Hours) bright screen exposure. All Subjects were asked to arrive half hour before the study, where the whole procedure was explained to them.
During the dark adaptation laptop screens were turned off for 30 minutes. EEG, KSS and VAMS were performed on hourly basis. All the participants remained on the seating position for 5 hours therefore, ten minutes rest was provided twice in the study followed by cognitive tasks. Each cognitive task lasted for 30 minutes. To get more exposure on eyes a short movie (40 minutes) with white background was shown between the two cognitive tasks.

Fig 1.1

Fig 1.2

Fig1.3

Fig 1.1 photograph of white backlit LED laptop HP p077 with diagonal length 15.6 inches; Fig 1.2 participant during the screen exposure performing cognitive tasks from a particular distance; Fig 1.3 EEG electrodes placed on participants scalp using 10-20 system.

2.2 Subjective and Objective Assessment

Visual analogue mood scale (VAMS) was used as a subjected measure to evaluate mood. This 100mm vertical scale was composed of seven sub-scales with labels "Happy-Sad" "Miserable-Satisfied" "Peaceful-Distressed" "Excited-Bored" "Calm-Afraid" "Peaceful-Angry" and "Sleepy-Alert" on the both ends. A vertical scroll bar was placed between these two labels which provided values from 0-100. On the left side there was a male face with different expressions which changed as scroll bar is dragged. For each of the scales user had to adjust their facial expression that best reflect their mood. For assessment all the scales were merged by taking mean value to form a single scale with labels "Pleasant-Unpleasant"
Karolinska Sleepiness Scale is a 9-point self-assessment scale. It is used very often in sleep measurements. Subjects were asked to rate their drowsiness at hourly intervals. KSS [2] is ranked from "1 to 9" with labels "extremely alert" to "extremely sleepy". Only odd numbers are labelled in the original scale. In modified KSS scale even and odd both numbers are labelled hence it was used during the study.

To objectively analyse sleep, 5 minutes EEG was done (2 minutes eyes close; 3 minutes eyes open). EEG data was collected and stored offline from frontal "Fz", Central "Cz", parietal "Pz" and occipital "Oz" derivations. EEG was recorded using 24 channels Clarity braintech system with real time video recording feature. Electrodes were placed on the scalp using 10-20 international system. Adhesive and conductive gel/paste was used to make stable contact with the scalp. Low pass filter was set to 1Hz while high pass filter was set to 70Hz. Gain was set to 7.5μV/mm and notch filter was turned ON during the recordings. EEG data was analysed using biopac student lab (Acqknowledge version 4.1). Artifact free data were manually detected from 3 min eye opening session. EEG data was segmented into small epochs of 10 seconds. Digital filters were used to filter unwanted frequency bands. Then ten second artifact free data was further subjected to power spectral density using fast fourier transform routine(FFT). Spectral power was calculated for four EEG derivations Fz, Cz, Pz and Oz.

2.3 Cognitive Performance

Reaction time task was used to measure sustained attention [21] that is ability to focus on a single task. In this task red light was shown on the screen, participates were instructed to click the mouse as soon as red light turns green. Five trials were taken from each candidate for each time the task was performed. For data reduction mean value of five trials was calculated for each individual.

Number memory task was used to quantify working memory [3, 17]. In this task a random number was displayed on the screen followed by 4 seconds delay, users were told to memorize that number and type the digits in the response window. Number of digits increased for each correct answer. This task ended when wrong digit was entered in the response window. An average person could memorize up to 7 digits of number. The idea behind this task was to check the effects of blue light on working memory.

Short term memory was assessed by verbal memory task. Instead of numbers words were shown in this task. With each word displayed on the screen there were two options namely "seen or new", participants had to select one option out of these two using mouse button. With every correct answer score "1" was added to the result and with each wrong answer "1" chance was deducted. Total three chances or lives were given before the task terminates.
An auditory task was also used to check auditory response time. Three random words were displayed on the screen. Users were advised to hear the word announced by the virtual voice and click the correct word out of three. . Everyone was instructed to go as fast as they can. Score "1" was given for every correct response. After every response there was a gap of 2 seconds. Total time duration of this task was 2 minutes.

Active memory was tested via visual memory task. A matrix of "6×6" that is 36 tiles were displayed on the screen. 18 number pairs were hidden behind 36 tiles. Goal of this task was to find out matching pair of the numbers as soon as possible. For this participants were told to visualize the location of a particular number and find its matching pair. Time taken to perform this task was noted in seconds.

Explicit memory task was sampled via word pair learning [4] task. Explicit memory is subdivision of long term memory [5] and also known as declarative memory. A set of 24 word pairs were shown to the participants before the task. They were asked to imagine a relationship between each word pair and memorize as many as possible. At the end of the session a different set of 30 word pairs were shown to them which consisted of "18 new" and "12 old" word pairs. For each word pair volunteers had to response "(A) It was never shown before (new pair)" or "(B) It was shown before (old pair)". Assessment was done on the basis of correctly answered new and old word pair percentage.

2.4 Statistical analysis

Statistical analysis was performed using SPSS Statistics version 20 and Minitab. Statistical analysis was carried out for each task (number memory, verbal memory, visual memory, reaction time task, auditory task, and word-pair learning) including mood and sleep scale. General linear modelling repeated measure (r-anova) was preferred for factors screen (LED screen, blue light filter screen), time, derivations (Fz, Cz, Pz, Oz) and tasks.

Table 1. Analysis of variance of cognitive tasks, karolinska sleepiness scale, and visual analogue mood scale

Analysis of variance (Factor-Screen)

Variable	*KSS*	*VAMS*	*Sustained attention*	*Number memory*	*Verbal memory*	*Visual memory*
F-value	$F_{1,60} = 4.43$	$F_{1,68} = 4.08$	$F_{1,24} = 4.62$	$F_{1,12} = 5.52$	$F_{1,24} = 4.97$	$F_{1,12} = 4.76$
P- value	$P = 0.040$	$P = 0.047$	$P = 0.042$	$P = 0.037$	$P = 0.035$	$P = 0.049$

Table 2. Analysis of variance of EEG (factors and interactions)

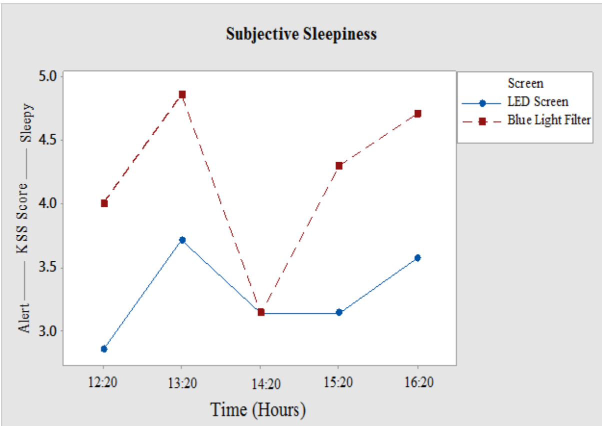
Analysis of variance (EEG)

Variable	*Screen*	*Channel*	*Channel × Screen*	*Time × Screen*
F-value	$F_{1,240} = 4.36$	$F_{3,240} = 11.60$	$F_{3,240} = 3.12$	$F_{4,240} = 3.69$
P- value	$P = 0.038$	$P < 0.001$	$P = 0.027$	$P = 0.006$

3. RESULTS

Karolinska sleepiness scale was rated hourly and further analysed by repeated measure anova showed significant effect for "screen" ($F_{1, 60}$ = 4.43; P = 0.040), as represented in Table 1 but, no significance for time or interaction time versus screen. KSS mean score after first cognitive task (14:20 hour) was similar for both the screens but after second cognitive task (16:20 hours) it varied. From *Fig 2.1* it is seen that participants who performed on LED screen were more alert throughout the study as compared to participants who performed in front of blue light filter screen.

Mood ratings were also taken at same time intervals as KSS. Mood scale versus screen showed significant effect for factor "screen" ($F_{1, 68}$ = 4.08; P = 0.0470*)*. It acknowledged more unpleasantness in participants who were subjected to LED screen interface as compared to blue light filter interface. No significant effect was revealed for interaction screen versus time. It is clearly seen in *Fig 2.2* that mood of participants exposed to blue light filter is much pleasant than LED screen participants.



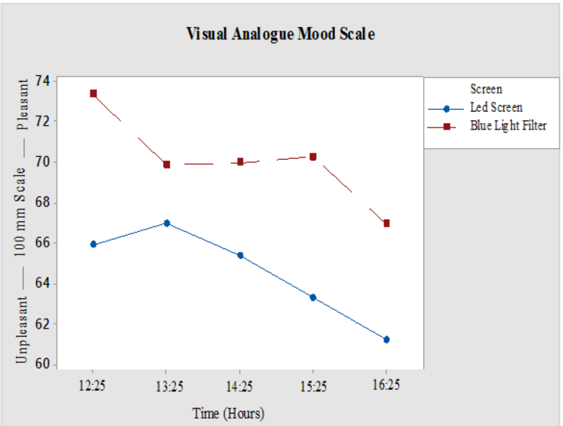


Fig 2.1 **Fig 2.2**

Fig 2.1 Subjective sleepiness score during different times of the day for two type of screen interfaces (LED screen, Blue light filter screen). Fig 2.2 Visual analogue mood scale ratings on hourly basis for two screens interfaces (mean value n = 7).

For EEG power density analysis multi-factors; derivations, screen interface, time with multi-levels were tested using general linear modelling. Significant values were observed for factors, derivation ($F_{3.240}$ = 11.60; P < 0.001), screen ($F_{1, 240}$ = 4.36; P = 0.38) and interactions, derivation versus screen ($F_{3, 240}$ = 3.12; P <0.03) and time versus screen ($F_{4, 240}$ = 3.69; P = 0.006), data revealed in Table 2. Results showed that EEG delta-theta activity was more prominent in frontal region compared to others, as shown in Fig 3.1. Further analysis of frontal region (Fz versus screen, time) revealed significant value for factor screen ($F_{1, 60}$ = 5.10; P = 0.028,). From Fig 3.2 it is clear that EEG power increased only for blue light filter participants and attenuated for LED screen users except at 14:15 hours where blue light filter participants were more alert after their first cognitive task. But after second cognitive task at 16:15 hours EEG power dropped for blue light filter participants.

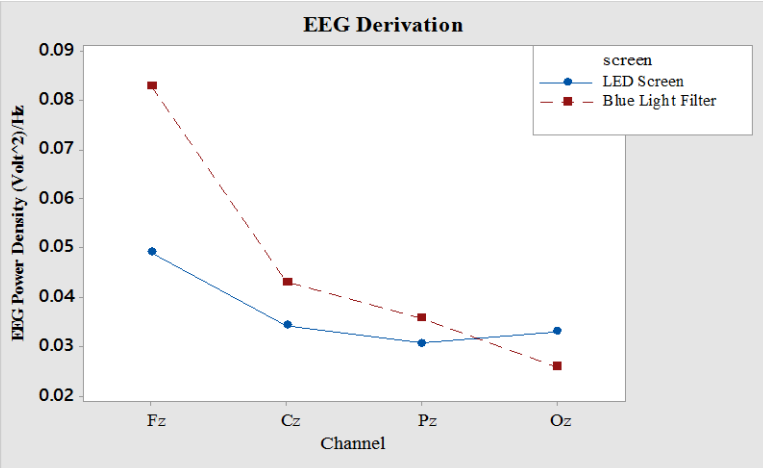


Fig3.1

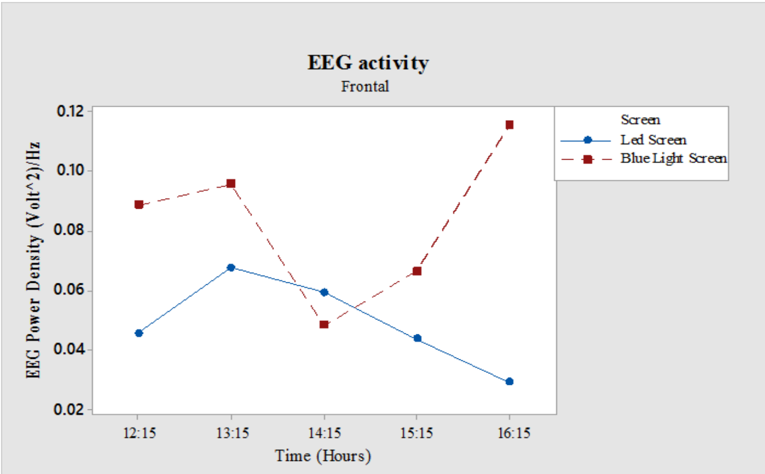


Fig 3.2

Fig 3.1 EEG derivation plot between channels (Fz,Cz,Pz,Oz) and power density for LED screen interface and Blue light fitter screen interface. Fig 3.2 EEG power versus time plot for two screen interfaces (mean n = 7).

Number memory task (marked as working memory) did not reveal any significant difference for time of the day therefore, tasks were independently compared for factor screen which revealed significant difference for screen ($F_{1, 12} = 5.52$; $P = 0.037$). From Fig 4.1 it is clear that, in first task participants subjected to blue light filter screen scored much better than LED screen participants. But performance of participants who were exposed to LED screen increased with time and they scored more than blue light filter participants in second task. Verbal memory task didn't yield differences for factor time and interaction of time and screen, but it yielded tendency for screen ($F_{1, 24} = 4.97$; $P = 0.037$). Verbal memory performance gradually decreased for both the screens but scores of blue light filter screen were higher than LED screen throughout the tasks. Difference in scores for both screens interfaces can be seen in Fig 4.2. Sustained attention shown in Fig 4.3 indicates that reaction time significantly increased for participants who were subjected to blue light filter screen. For general linear model, (reaction time versus screen, task) factor screen revealed ($F_{1, 24} = 4.62$; $P = 0.042$), as illustrated in Table 1. Task versus reaction time did not suggest any significance. While when tested with one-way anova (reaction time vs screen) revealed significance for screen ($F_{1, 26} = 4.86$; $P = 0.037$). Visual memory or active memory task gave no evidence for factors screen and task but when further investigated it revealed significant difference for task 2 score versus screen ($F_{1, 12} = 4.76$; $P < 0.05$). Response time of LED screen participants was constant in both the tasks, as shown in Fig 4.4 whereas response time of blue light filter participants improved with time. Therefore significant difference was found during second task for both the screen interfaces. Finally, auditory task and word pair learning task did not reveal any significance differences, both (LED screen and blue light filter screen) group performed equally in these tasks (data not revealed).

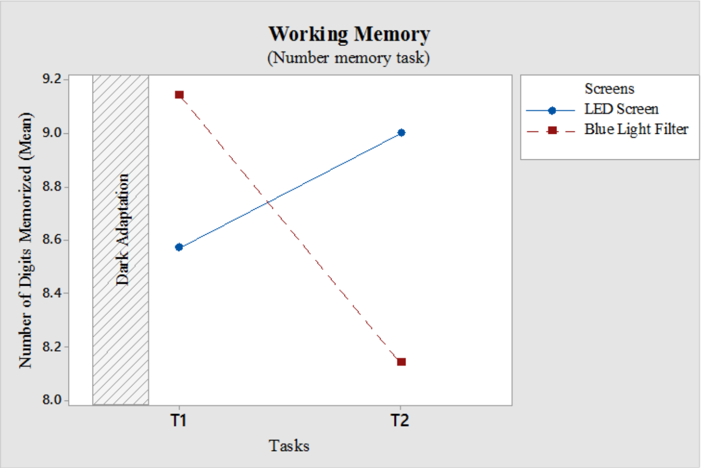


Fig 4.1

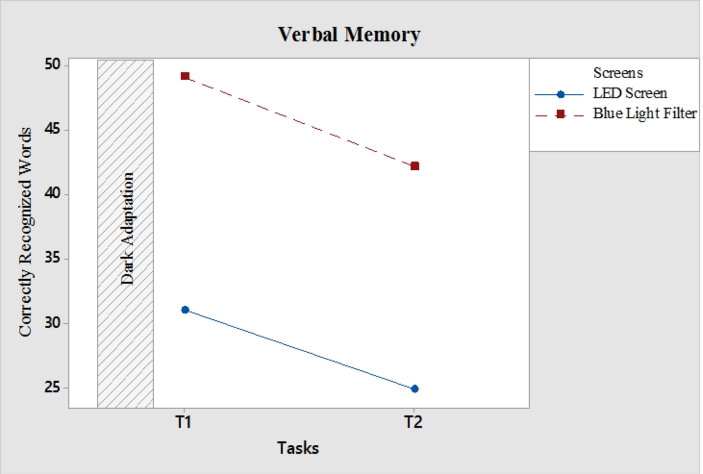


Fig 4.2

Fig 4.1 Number memory task for the assessment of working memory. Fig 4.2 Response of participants subjected to LED and blue light filter screen during verbal memory task.

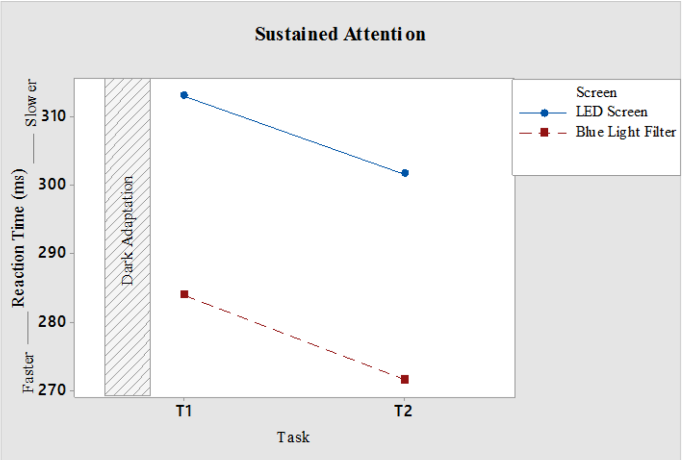


Fig 3.1

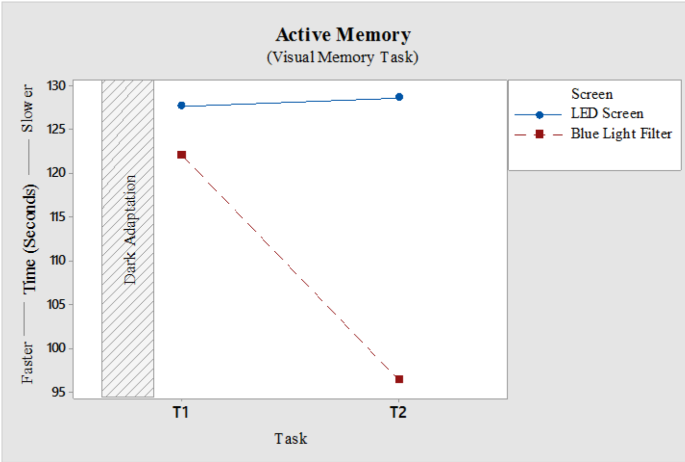


Fig 3.2

Fig 4.3 Reaction time task to measure sustained attention of participants. Fig 4.4 Active memory task is assessed by Visual memory task (mean value n = 7).

4. DISCUSSION

Here it is demonstrated that exposure to LED screen attenuates mood as compared to blue light filter screen. Throughout the whole study, group of participants who were exposed to LED screen felt unpleasantness whereas when the same group was exposed to blue light filtered screen they felt more pleasantness. No other parameters were changed except the type of screen interface which indicates that blue light has significant impact on mood. Similarly, karolinska sleepiness scale was also ranked at the same time of mood assessment, showed difference between screens. Although there was a moment when scores of both the groups were same but overall, the group exposed to LED screen stayed more alert than other.

Using sustained attention task new findings were revealed. Reaction time is associated with attention and previous researches had suggested that blue light is good for attention. During the study, it was observed that LED screen group performed slower in both the cognitive tasks but blue light filter participants maintained to score faster in both tasks. In visual memory and verbal memory tasks, performance of blue light filter group was consistently better than LED screen group. It provides information that blue light is not good for short term or active memory. Although a correlation between memory and attention was not established. But in working memory task which was assessed by number memory it was clearly seen that participants subjected to LED screen were able to memorize more number of digits with increase in exposure time, which concludes that blue light is good for number memory. An average person can remember numbers up to 7 digits, but if subjected to blue light the average value could be increased. Auditory and word pair learning tasks were not able to distinguish any difference between two types of interfaces. In auditory task both the groups performed similar, although blue light filter group was able to respond faster as their reaction time was much faster, but there was no significant difference found when analysis of variance was performed. Similarly, word pair learning task (explicit memory) was unable to establish any connection between correctly answered new and old word pairs. Percentage of correctly answered new and old word pairs was nearly equal for both the screen interfaces.

EEG delta-theta activity was mostly observed in the frontal region of brain. Central, parietal, and occipital region did not reveal any significant change in these activities. Increased power density in the range of 1- 7 Hz was found for group of participants who were exposed to blue light filter. Increase in EEG power density points towards dizziness. If short time exposure during daytime [9] can affect memory performance and sleep of participants then people who work on LED devices for long time are in greater risk of circadian misalignment which leads to sleep problems [11].

Other than sleep blue light also affects mood, memory, and alertness. Increased alertness is a good thing during daytime. It might help to perform better, but exposure to blue light also tends to decrease active memory and reaction time. India is a leading country with two major industrial components; IT services and Business process outsourcing (BPO). In these sectors, people work for 8 to 9 hours straight. These adolescents are spending their leisure time in front of computers and even multiple screens. This amount of exposure to artificial blue light can cause phase shifts, depression, memory dysfunction, and sleep deprivation. Similarly children spend their time in front of game consoles are also affected by blue light. To find an optimal solution and eliminate effects of blue light on brain performance further research is required.

5. CONCLUSION

It was found that exposure to LED screen attenuated mood and memory performance of participants. Study conducted during daytime revealed significant differences for mood, attention, memory, and sleep. Therefore, usage of a blue light filter which can block short-wavelength light is the best approach to avoid blue light hazards.

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