Original Research Article

Effect of Lighting on Concentration of Medical Students: A Randomised Controlled Trial

ABSTRACT

Aims: To determine the effect of lighting on concentration in college students.
Study design: Randomised controlled trial
Place and Duration of Study: Melaka-Manipal Medical College (MMMC), Muar Campus, Johor, Malaysia in July 2016.
Methodology: 50 students were randomly chosen and then assigned to intervention and control groups equally via randomisation. 41 students participated in this study. Participants of both groups were required to perform d2 Test of Attention and answer a structured questionnaire. The intervention group was placed in room with low luminosity while the control group was in a room with higher luminosity. Data were analysed using SPSS version 18.
Results: The intervention group had a mean score of 526.9 for concentration performance, which was lower than that of the control group at 615.3. The mean for error percentage of the intervention group was 0.10, whereas the control group had a lower mean of 0.03 for the same outcome. In general, the intervention group had significantly weaker concentration and more errors made as compared to the control group.
Conclusion: The results of this study highlight the positive effect of a higher lighting intensity has on concentration. Thus, it is recommended that educational institutes take into consideration the intensity of lighting as an important factor when setting up and designing their classrooms.

Keywords: Concentration, attention, d2 test of attention, light intensity

1. INTRODUCTION

Concentration is the ability to give one's attention or thought to a single object or activity at a time and is an important element to facilitate the learning process [1,2,3]. It is affected by both internal (random internal thought) and external factors (noise, lighting, emotions, colours and etc.) [4]. Thus, many studies were conducted in schools among the Western populations on the effects of external factors on concentration ability of students [5,6,7].

Lighting has been described as an agent in improving cognitive performance [8]. The importance of lighting for performance in humans is well established and many researches have indicated that lighting can affect people's mood and alertness [9,10,11,12]. Meanwhile, other studies have found that the degree of illumination is one of the modifiable factors to provide a more conducive and optimal environment for concentration [13,14].

These effects of lighting on human body make one wonder how lighting affects a student's concentration. While the literature available suggests that lighting can affect the ability to concentrate, most studies were conducted on young and school-going children [6,15]. Thus, this study was conducted to determine the effect of lighting on concentration among college students.

2. METHODOLOGY

In July 2016, we conducted this randomized controlled trial among medical students of Melaka-Manipal Medical College (MMMC) in Muar, Johor, Malaysia. MMMC was established in 1997 and is a leading medical education provider, the single largest contributor of doctors to the Malaysian healthcare system. Currently MMMC has two faculties namely the Faculty of Medicine (MBBS) and The Faculty of Dentistry

(BDS) while offering a pre-university course i.e. Foundation in Science Programme (FIS). MMMC has a total of three campuses namely in Manipal, Melaka, and Muar, which house around 2000 students and faculty in total [16].

We selected our study population which consisted of students from the Muar campus of MMMC. Using the values $\bar{x}_1$=206.89, $\bar{x}_2$=178.32, and SD=30.39 from a previous similar study [6], we calculated the minimum sample size of 18 (rounded up from 17.8) persons per arm using the following formula [17]:

$$n = 2C/\delta^2 + 1, \quad \text{where} \quad \delta = (X_1 - X_2)/SD \text{ and } C = 7.84$$

The minimum number of participants for both arms was 36 persons. We proceeded by selecting a total of 50 students from the student population of 205 students via simple random sampling using a scientific randomizer. We approached the selected students personally and obtained their consent. The inclusion criterion was the willingness of students to participate whereas the exclusion criteria were unwillingness to cooperate and not attending the session conducted.

We randomly assigned the 50 selected students equally into the intervention and control groups once again using the scientific randomizer. To maintain the single-blinding characteristic, we only informed the students that they belonged to either Group A (Intervention) or Group B (Placebo).

2.1 Interventions

Luminosity or lux (lx) is a measure of the overall illumination of a scene. One lux is equal to the intensity of the light hitting a one metre squared object placed one metre away from a candle. The higher the lux value, the greater the intensity of light falling on the scene [18]. We exposed the intervention group to low degree of illumination i.e. low lux value. To achieve this, we selected a room and manipulated its lighting by turning the lights on or off.

The room we chose had 16 light bulbs arranged in sets of 2 light bulbs. The bulbs used were Panasonic energy saving bulbs (Model no: FL40SS.D/36), each of which had a power of 36W and gave off light with a luminosity rating of 2600 lumens and colour temperature of 6500K [19]. We selected a room without windows and sealed off the glass panels on the doors to eliminate natural light from entering the room.

We only kept two sets of lights (4 bulbs) switched on during the intervention session in which the recorded luminosity measurement at desk level was 15 lx. For the control group, we turned all the lights in the room on to produce a measured luminosity of 450 lx at desk level. We measured the luminosity in the rooms using a phone-based digital lux meter application called ‘Lux Meter’ that had been found to produce accurate readings in another study [20].

2.2 Outcome

We measured the ability to concentrate of subjects under different lightings using the d2 Test. The d2 Test measures processing speed, rule compliance, and quality of performance, thus allowing for a neuropsychological estimation of individual attention and concentration performance [22]. The reliability of the test has been proven to be very high, and the validity of the technique has been documented by a number of research studies, as evident by the internal consistency of the total number of items processed ranging from 0.84 to 0.98 along with a test-retest reliability of 0.87 [21,22].

The d2 Test consists of 14 rows, each containing 47 characters; giving a total of 658 items. Ten different characters are used in the d2 Test, which are made up of combinations of the letters "d" and "p" with one to four dashes, which are in turn arranged either individually or in pairs, above or below each letter. The subjects were required to scan across the rows from left to right to identify and to mark all items

consisting of “d’s” with two dashes. The subjects were asked to work as quickly as possible without making mistakes. The processing time per row was set at a 20 seconds, which we timed using a stopwatch. At each 20-second interval, we instructed the subjects to shift to the following row regardless of whether the current row had been completed or not. The total administration time for the d2 Test was four minutes and forty seconds. We administered the test in groups consisting of four to eight subjects.

From the d2 test sheets, we were able to obtain several scores namely, (1) Total Number of Items Processed (TN), which was the number all items that were processed, both relevant and irrelevant ones; (2) Raw Score of Errors (E), which was the sum of all mistakes in the forms of errors of omission (number of relevant items that were missed, E1) and errors of commission (number of irrelevant items that were marked, E2); (3) Percentage of Errors (E%) which was the proportion of errors (E) out of total number of items processed (TN); (4) Total Number of Items Minus Error Scores (TN-E). From these calculated scores, we managed to derive two other test scores which were (5) Total Number of Items Minus Double of Error Scores (TN-2E); and (6) Concentration Performance (CP), which was derived from the number of correctly crossed out relevant items (d2) minus the errors of commission (E2) [23].

Upon completion of the d2 test, participants were required to answer a two-part self-administered structured questionnaire. We collected sociodemographic data in Part 1 of the questionnaire which included age, gender, birth order, monthly allowance, number of meals per day and number of hours of sleep per day. In Part 2, we included questions that assessed various perceptions of the participants towards their experience during the session. Part 2 consisted of four sections, A, B, C, and D. Section A contained five items that assessed how well the participants had understood the test. Section B contained eight items to assess how the participants felt during the test in the particular conditions of the room. Examples of the items asked in this section included if they felt comfortable in the room and if they experienced headaches due to the conditions of the room. Section C contained seven items that asked participants about their perception on their respective performances in the test. These include items about their ability to think clearly and their evaluation of their own alertness during the test. Lastly, section D contained two items regarding the opinion of participants on the test whether they felt it was organised and suitable.

We utilised a Likert scale response format with responses ranging from “strongly disagreeing” to “strongly agreeing” and scores ranging from “1” to “5” respectively. For each item that was worded negatively, we reversed the score accordingly. Then, we summed up the responses for each of the four sections. A higher total score in section A meant that the participants had a higher understanding of the test, while in section B, a higher total score meant that the participants felt the conditions of the room had no effect on them. In section C, a higher total score meant that the participants performed well according to their subjective perception. Lastly, a higher total score in section D showed the participants felt the test was suitable.

2.3 Data Processing and Analysis

We processed the data using Microsoft Excel and then proceeded to data analysis using SPSS version 18. We presented our data using frequencies and percentages as well as means and standard deviations in a tabulated form. We used unpaired t-test statistical analysis for the outcomes in the intervention and control group which were the scores of d2 Test and scores of Part 2 of the questionnaire. The level of significance was set at 95% (P value <.05).

2.4 Ethical Approval and Consent

We were granted approval to conduct the study by the Research Ethics Committee of Melaka-Manipal Medical College in July 2016. We had also obtained written permission from the administration of Melaka Manipal Medical College (Muar Campus) for the use of their premises to conduct the study. All the students were voluntary participants of the study and had given their written consent. We also assured the confidentiality of all data collected during this study.

3. RESULTS

The total number of participants was 41 participants, among which the mean age was 22.9 years with standard deviation of 0.53. The majority of the participants were females, constituting 58.5% of the participants. In terms of ethnicity, the largest group was Malay who made up 39%, followed by Chinese and Indian, who accounted for 26.8% and 24.4% respectively. Others indigenous groups made up the remaining 9.8%. Descriptive statistics of all participants in the study are shown in Table I.

Table I: Descriptive statistics of basic variables among participants

Variable	Values
Age (Mean ± Std Deviation)	22.9 ± 0.53
Gender	
Male	17 (41.5%)
Female	24 (58.5%)
Ethnicity	
Malay	16 (39.0%)
Chinese	11 (26.8%)
Indian	10 (24.4%)
Others	4 (9.8%)

By comparing the sociodemographic characteristics between the intervention and control groups, the mean age of the intervention was 23.0 years, which is found to be higher than 22.8 years of the control group. In terms of gender, there were 11 (52.4%) males in the intervention and 6 (25.0%) of them in the control group. In this study, Malays constituted the highest percentage in control group (52.4%) followed by the Chinese (19.1%), Indians (14.3%) and others (14.3%). In the intervention group, both the Chinese and Indians made up 35% of the group followed by Malays (25%) and others (5.0%). However, the differences between the intervention and control group in terms of age, gender and ethnicity were not significant. Details are tabulated in Table II.

Table II: Comparison of sociodemographic characteristics between intervention and control

Variable	Values		*P* value
	Intervention	Control	
Age (Means ± SD)	23.0 ± 0.51	22.8 ± 0.53	.26
Gender			
Male	11 (55.0%)	6 (28.6%)	.09
Female	9 (45.0%)	15 (71.4%)	
Ethnicity			
Malay	5 (25.0%)	11 (52.4%)	Reference
Chinese	7 (35.0%)	4 (19.1%)	.13 ~
Indian	7 (35.0%)	3 (14.3%)	.11 ~
Others	1 (5.0 %)	3 (14.3%)	.99 ~

~ Fisher exact test was used since expected cell count <5

From the scores of the d2 test, the intervention group had means of 530.3 and 472.5 for TN-E and TN-2E respectively, which were significantly lower than the control group with means of 619.0 and 597.1 respectively. The intervention group had a mean score of 526.9 for concentration performance, which was also lower than that of the control group at 615.3. Other than that, the mean for error percentage of the intervention group was 0.10, whereas the control group had a lower mean of 0.03 for the same outcome. In general, the intervention group had weaker concentration and more errors made as compared to the control group. The significant differences in scores between the intervention and control groups are depicted by Table III and Figure I.

Table III: Quantitative comparison of outcomes of the d2 test between intervention and control groups via independent t-test

Outcomes		Mean (SD)	t test	*P* value
TN-E	Intervention	530.3 ± 71.8	-5.15	< .001*
	Control	619.0 ± 31.9		
TN-2E	Intervention	472.5 ± 95.6	-5.44	< .001*
	Control	597.1 ± 42.8		
CP	Intervention	526.9 ± 71.1	-5.19	< .001*
	Control	615.3 ± 31.6		
Error %	Intervention	0.10 ± 0.06	4.83	< .001*
	Control	0.03 ± 0.03		

** Significant finding, (P value <.05)*

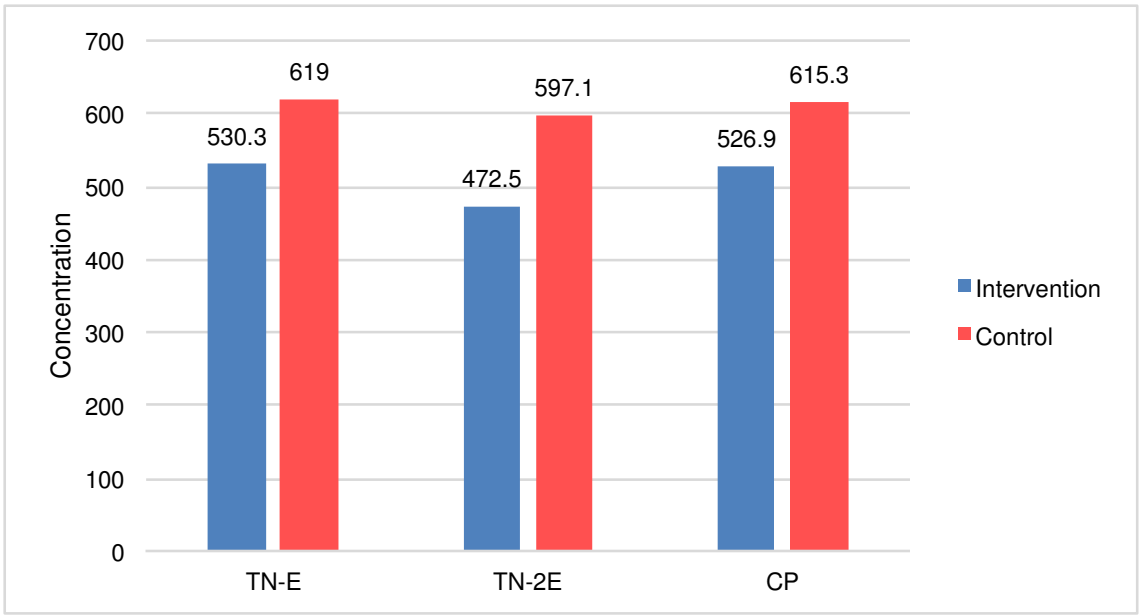

Figure 1: Comparison of concentration test scores among Intervention and Control

After correcting for the confounders, namely gender, age, ethnicity and the number of hours of sleep the students had the day before the RCT, the intervention group was found to have a significantly lower level of concentration performance (CP), as compared to the control group as shown in Table VI.

Table VI: Multiple linear regression analysis of lighting intensity on concentration performance

Variables		Unstandardised Coefficients	t-test	*P* value	95% Confidence Interval	
					Lower Bound	Upper Bound
(Constant)		631.33	1.41	.17	-277.38	1540.05
Intervention		-87.45	-4.18	<.001*	-130.01	-44.89
Gender		3.50	0.17	.87	-38.20	45.20
Age		-2.26	-0.12	.91	-40.36	35.84
Ethnicity	**Malay**	38.80	1.15	.26	-29.79	107.39
	Chinese	31.23	0.88	.39	-40.89	103.35
	Indian	19.94	0.53	.60	-56.82	96.69
Number of hours of sleep		0.30	0.03	.97	-17.68	18.27

** Significant finding, (P value <.05)*

From the same table, a prediction model can be generated, which enables the estimation of the concentration performance of a student, as shown in the equation below:

Concentration Performance = 631.33 - 87.45(Intervention) + 3.50 (Male) - 2.26(Age)
+ 38.80(Malay) + 31.23(Chinese) + 19.94(Indian)
+ 0.30(Hours of sleep)

For example, the concentration performance score in d2 test under exposure to illuminance of 15 lx of a 24-year-old Malay female, who had 8 hours of sleep the night before, would be 530.84.

The statistical analysis of perception of participants towards various aspects of the RCT session is shown in Table V. In this table, a higher mean score is indicative of a more positive outcome whereas a more negative outcome would be indicated by a lower mean score. Regarding comprehension of the test conducted, the control group averaged at 16.7 whereas the intervention group averaged at 19.5. The control group also found the room conditions to be more favourable, giving a mean score of 30.3, compared to the intervention group, which had a mean score of 24.6. As for their performance, the control group had more positive perception with a mean score of 22.3 compared to the intervention group which scored 19.6. With regards to the suitability of the test, there was no significant difference between the two groups.

Table V: Statistical analysis of perception towards various aspects of RCT session

Perception towards		Mean ± SD	t-test	*P* value
Comprehension of Test	Intervention	19.5 ± 3.6	2.45	.02*
	Control	16.7 ± 3.8		
Room Condition	Intervention	24.6 ± 5.1	-3.13	.003*
	Control	30.3 ± 6.5		
Performance	Intervention	19.6 ± 3.7	-2.57	.01*
	Control	22.3 ± 3.1		
Suitability of Test	Intervention	8.5 ± 1.4	0.95	.35
	Control	8.0 ± 1.6		

** Significant finding, (P value <.05)*

4. DISCUSSION

The intervention group, which underwent the d2 Test in the room with lower light intensity, had a significantly lower mean TN-E as compared to the control group in higher light intensity. TN-E is the total

number of item processed minus both errors of commission and omission, and is a measure of quantity of work completed after correction for errors [24]. It provides a reliable correlation between accuracy and speed of performance [25]. TN-2E is another similar parameter, which doubles the error score, to correct for total performance [26]. Thus, the results for both TN and TN-2E imply that subjects in the control group, who were exposed to light of higher intensity, were faster and more accurate in completing the task, thus giving a higher productivity.

In addition, the intervention group had lower score for concentration performance, as compared to the control group. Concentration performance takes both accuracy of performance and coordination of speed into account. It is the most reliable measurement of concentration as it is not sensitive to extreme scores due to incidental coincidences [25]. In other words, the control group, which performed the d2 test in light, had higher level of concentration than the intervention group.

On the other hand, the intervention group had a higher error percentage than the control group. Error percentage is a measure of inhibitory control, rule compliance, carefulness and quality of performance in general [25]. Hence, the control group, with a lower mean score for percentage of errors, indicated that the subjects had better accuracy and attention level, hence higher quality of task performed [24,25].

The results of d2 Test thus show that the subjects who were exposed to higher light intensity had a higher level of attention and concentration as compared to subjects who performed the same task under lower light intensity, as in accordance with results of a few similar researches [6,27]. Light is said to be the most important environmental input, after food and water, in controlling bodily functions [28]. Other than a strong enabler for visual performance, light also regulates mood, focus, motivation, concentration and alertness, thus increasing productivity [29,30].

A sound explanation to the findings of our research would be the effect of bright light exposure during daytime on subjective sleepiness of the subjects in control group, whereby light of higher intensity effectively replenished the subjects' energy and reduced their feeling of fatigue, thus improving their sustained performance and increasing their productivity [31,32,33,34]. Studies had shown that higher illuminance is more arousing than lower illuminance, both cortically and behaviorally, due to the waking effect of higher light intensity on the central nervous system [35,36]. Indeed, light-induced improvement in subjective alertness was found to be linearly related to responses in the posterior thalamus [37]. These resulted in subjects in the control group having a higher level of concentration when compared to the intervention group.

Another plausible theory that explains the relationship between light intensity and the level of concentration of our subjects involves the role of melatonin, a hormone which has the highest plasma level in the human body during the peak of rest phase of human rest activity cycle [38]. It has been hypothesized that melatonin attenuates the suprachiasmatic nucleus-dependent mechanisms responsible for promoting and maintaining cortical and behavioral arousal at particular times in the circadian cycle, thus causing a depressant effect upon arousal, attention and motor activity [27,38]. This explains the lower level of concentration among subjects in the intervention group, who were exposed to light of lower intensity. Contrarily, exposure to sufficiently bright light could hypothetically increase alertness due to decreases in circulating and CNS melatonin levels [32]. In fact, a study in the USA showed that variations in lumination within the range of typical, ambient, room light of 90 to 180 lux could have a significant impact on subjective alertness, which is a dose-response relationship that had been positively correlated with the degree of melatonin suppression by light [27,39].

Along with the results of the test, we also found significant differences between the subjective perception of the intervention and control group with regards to various aspects of the experiment. The test was found to be more comprehensible to the intervention group participants compared to control group participants. This is surprising as it had been noted in previous studies that students cannot focus and were sleepy when they are in a poor lighting environment, thus causing their comprehensibility and performance to be affected [40]. One plausible theory would be the decrease in visual input in lower light

intensity had enabled the intervention group to focus more on the sense of hearing, thus enabling them to understand the instructions better.

We also observed that the control group felt better and less affected by the conditions of the room compared to the intervention group. This suggests that good lighting can create a calm atmosphere without an oppressive feeling [41]. Furthermore, adequate light level can prevent visual discomfort such as excessive straining of the eye or squinting which can lead to headache [42,43].

Another significant finding was in term of their subjective personal performance. The control group felt they had performed better compared to the intervention group whereas participants from the intervention group had reported that they were more relaxed, and were able to think more clearly and experienced increased concentration level. This may be due to the good lighting, which had provided motivation for the participants to perform better [40]. Another explanation is that visual performance is generally improved when people can see the task clearly [44].

There are a few limitations in our study that should be addressed for more reliable results. Our study had only investigated light as a single factor affecting students' concentration. Among the limitations there could be the presence of other factors such as stress that may have an adverse effect on the ability to concentrate. This was because participants were selected from five different clinical posting groups and may be exposed to varying amount of stress. Personal problems could be another possible source of stress [45]. On the other hand, we were unable to acquire a lux meter due to the limited resources [20]. The age of the light bulb was also a limitation as older light bulbs may be worn out and this corresponds to lower lumen values [46]. Another limitation was that we only took into account the intensity of lighting but did not look into other aspects of lighting such as glare and temperature. Also, the students were told to wear their respective visual aids during the vision but their visual acuity was not tested.

As such further research into this subject may be directed towards the possible effects of the temperature of lighting, glare as well as the effects of natural lighting on the ability of a student to concentrate.

5. CONCLUSION

The findings of this study highlight the positive effect of a higher lighting intensity on a student's concentration. Thus, it is recommended that educational institutes take into consideration the intensity of lighting as an important factor when setting up and designing their classrooms in order to ensure that the concentration levels of students are not negatively affected.

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