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Visual Performance and Illuminance: A Case Study amongst First Year Students

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Abstract

Purpose: This research investigated the effect of illumination on visual performance and visual fatigue in using liquid crystal display (LCD) of personal computers and paper print.

Methodology: The research was a descriptive cross sectional study. Two rooms were selected randomly for the study: study room and hall room. 25 first year students were randomly selected for the study. Three illuminance levels were used: 30 lux (hall room illumination), 130 lux (study room illumination) and 1440 lux ('sunlight illumination' – still in study room).

Results: All the rooms used for the study had electrical illumination available. In the each room electrical illumination was by compact fluorescein lighting (CFL). There were no shadows cast which interfered with reading at the various illumination levels. Legibility testing showed that all participants were able to identify the same optotype under each illumination level. Visual Accuracy testing showed that illumination affected visual accuracy significantly with paper display than with computer display. Students were more accurate on the paper display than on the computer display across all illumination levels. Search time results showed that participants were generally faster with computer display than with paper display. However search time significantly decreased with paper display across all illumination levels. Visual discomfort results showed that illumination had an effect on discomfort with visual discomfort generally increasing with LCD screen than with paper display across the illumination levels.

Conclusion: Visual performance increased with increasing illumination and was better with paper display than with LCD screen of a computer.

Recommendations: Illuminance levels should be increased by proper lighting procedures and alternatives to laptop computer displays which provide optimum visual performance like paper print such as E-paper, should be sought out.

Keywords: Illuminance; Visual performance; Optotype; First year students; Study room

Background Information

Light is a radiant energy that has the ability to cause not only humans but many living creatures to see by exciting light sensitive structures in the eye (retina in the case of humans) and creating a visual sensation. Light, which is basically that aspect of radiant energy to which the eye responds as a visual experience, is called *luminous radiation* [19]. Only electromagnetic radiation with a wavelength between 380 and 760 nm is visible to the human eye [22]. Human beings are continuously bombarded by electromagnetic energy, including waves from radio transmitters, infrared rays from heat lamps and ultraviolet rays from the sun and quartz lamps, without receiving any visual sensation as a result of being in contact with these sources. It is only a portion of this *electromagnetic spectrum* that determines the visible world.

Light has a dual nature, being considered both an electromagnetic wave, which can vary in frequency and wavelength, and also a series of discrete packets of energy, called photons [22]. Both forms of description are used in explaining how the visual system responds to light. In determining the sensitivity of the visual system to light, such as the minimum threshold of light detection, it is usual to refer to light in terms of photons.

Measurement of light or photometry is generally concerned with the amount of useful light falling on a surface and the amount of light emerging from a lamp or other source, along with the colours that can be rendered by this light [19]. Light can be detected using instruments like photodiodes and photomultipliers.

The illuminance of an object is the amount of flux density of light falling over a unit area. The unit of illuminance is foot-candles (FC). In modern usage, the amount of illumination, or illuminance, is referred to in terms of lumens per foot (Lux –when measurement is taken in meters) rather than candles per foot or foot-candles.

$$\text{FC} = \text{Lux} \times 0.0929 \quad \text{Foot-lambert (fL)} = 3.43 \times \text{Lux (cd/m}^2\text{)}$$

The basic function of the eye is to catch and focus light on to the retina thin photo sensory receptor cells [22]. Parts of the eye include the following:

A major goal in the study of human vision is to relate performance—for example, the ability to see fine detail—to the underlying anatomy and physiology [2]. In the same way a major goal in the study of human vision is to relate visual performance to illumination. Visual performance has traditionally been defined in terms of speed and accuracy of processing visual information [17]. The visual system can

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be said to be a system that assimilates a lot of information primarily visual. Thus visual performance should refer to the rate at which this visual information is assimilated. Inferred changes in speed and accuracy for different adaptation levels underlie the rationale for different illuminance levels recommended by national technical societies [19]. Visual performance is looked in this study under three categories which will be visibility, visual search and accuracy time and visual discomfort (fatigue). The goal in this study is to relate these categories under visual performance to illumination.

However it is important to note that illumination is not the only thing that affects visual performance. There are other variables that affect the visual performance of an individual apart from illumination. These include: light source, Character size, interline spacing and reading distance.

Light plays a significant role in creating a pleasant environment where students and teachers can interact and engage in the education process. Independent research has shown the benefits of good day lighting and of good artificial lighting to educational productivity in schools [14]. Proper lighting can enhance task performance, improve the appearance of an area, or have positive psychological effects on occupants.

Glare happens when one part of the visual scene is much brighter than the general brightness of the rest of the field of view [14]. A high source luminance, large source area, low background luminance and a position close to the line of sight all increase glare. Such glare can be of two types: disability glare and discomfort glare [14].

100 Hz modulation can adversely affect visual search performance even though subjects do not consciously experience it as flicker [14]. Establishing causative links between aspects of classroom environment and the factors mentioned is difficult, in part because of the practical and ethical difficulties in conducting controlled trials in classrooms [14].

Materials and Methodology

This study is a descriptive cross-sectional study of first year students in the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana for the 2020/2021 academic year.

The Study rooms of selected campus halls were studied.

Inclusion Criteria: Students in first year located in the selected halls of the university were sampled for the study.

Exclusion Criteria: Students who are not in first year were excluded.

Sampling Technique: Random Sampling was used to select the Hall and its study room. Random sampling was used to select students from the selected hall in the university. Random sampling was used to select a hall room for the study.

Sampling Size: The sample size was 25 students randomly selected from the selected hall for the study.

Ethical Consideration: Permission was sought from the school and hall authorities before the research is carried out.

Materials/Tools

The tools and materials used were:

A Snellen visual acuity chart

LVRC near acuity chart

Photo cell and illuminance gauge

Questionnaire (rating scale)

A Dell Laptop computer (Core i3)

A stop watch

Data Collection Techniques

Observations and documentation were the main data collection techniques used. The study room and hall room illumination source were identified and noted. The environment around the study room and hall room was explored to ascertain if there are any structures around it and to check if these structures were casting shadows on the study room windows. The direction and extent of shade being cast was noted. A photocell was used to measure the intensity of light (at desk level) at 5 points in the study room and also at the hall room. The average of the illuminance levels at the 5 different points in the study room and at 3 different points in the hall room constituted the average illuminance for each particular room. Average illuminance levels were taken at two levels in the study room. The first was when there was no daylight coming into the study room (in the evening preferably when most students do their learning or when all efforts are made to exclude sunlight from entering the study room) with only electrical illumination available. The second was taken during the day when there was no electrical illumination with only day lighting available in the study room. The next illumination level was inside the hall room. The average illuminance at desk level inside the hall room was taken at night to diminish the interference of sunlight illumination. In all three illumination levels were considered.

Patients were given instructions about the experiment which consisted of three parts in two folds: A legibility test, a visual accuracy and search test and a subjective visual fatigue assessment. All these tests were done under the three various illumination levels in two forms. The first consisted of print paper and the second group of tests were on LCD screens of laptop computers.

Legibility test: The 0.00 log MAR optotype was presented to all participants at each illumination level to be identified at 40cm.

Visual Accuracy and Search time test: A letter-search task was conducted to evaluate the legibility and assess visual accuracy and search time. A paragraph of alphabetic pseudo text with character size similar to the 0.00 Log MAR optotype size of Times New Roman type was used for the task, where 41 targets of character "q" were embedded in a random strings of letters, digits, punctuation marks, and space. The text was arranged in 26 lines. The font face that was used was Calibri (body).Character size was 3.4mm. Interline spacing was 3mm or 60%. Interline spacing was defined distance between two adjacent lines expressed as a ratio. Interline spacing and character size was the same in each case. Each participant was required to proceed with the following steps:

1. Adjust seat to his/her best comfort with both eyes gazing at the center of the screen or on the print paper 40cm away

2. Scan the text and identify the target "q" as accurately and quickly as possible and they will be given three paragraphs to read under each experimental condition in a specific amount of absolute time.

3. Repeat steps 1 and 2 for all display screens (whether LCD

screen or print paper) under the various illumination levels

In addition, a rating scale with six items was administered to collect subjective rating Accuracy was defined as the number of searched targets divided by the number of total targets. Subjective visual fatigue (visual discomfort) was determined by the total score of subjective rating of visual fatigue test which was administered to participants.

Statistical Package for Social Scientist (SPSS) software version 23.0 was used to analyse the data by way of Microsoft Excel in drawing graphs.

Results and Analysis

The main source of illumination for the study room was electrical illumination. However during the day time, a combination of both electrical illumination and daylighting was employed. Daylighting was employed by lifting up the curtains in the study room and allowing daylight to come into the study room. Electrical illumination was by compact fluorescent lighting (CFL). There were 6 lotus shaped electrical bulbs (75 Watts each) in the study room as of the time of the study arranged in three pairs across the length of the room (rope lighting). There were 6 pairs of windows in the study room which helped with daylighting. Two pairs of windows were in the north side of the Hall, one pair each were in the east and west side of the Hall. There were no shadows cast during the day when daylighting was employed that significantly opposed or affected visual tasks.

The main source of illumination for the selected hall room was electrical. During the day time, however, a combination of both electrical illumination and daylighting was employed when daylight was allowed in by opening the windows. Daylighting only could also be used during the day time. Electrical illumination was by 2U 20 Watt CFL. There was only one electrical bulb in the hall room as of the time of the study that was positioned in the top middle of the wall directly above the top bunk bed close the ceiling.

Three levels of illumination were engaged in this study. Two of these illumination levels were to be measured in the study room. These illumination levels were to be measured:

When there was no daylight coming into the study room (in the evening preferably or when all efforts are made to exclude sunlight from entering the study room) with only electrical illumination available

During the day when there was no electrical illumination with only daylighting available in the study room.

The average study room illuminance when there was only electrical illumination available (daylighting excluded) was 130 Lux (12.08 Fc). This was arrived at after taking the illuminance level at desk position at five points in the study room with only electrical illumination available. This illumination level will be known as study room illumination in the rest of the study.

The average study room illuminance when there was no electrical illumination with only daylighting available in the study room (windows opened) was 1440 lux (130.78 Fc). This was also arrived at after taking the illuminance level at desk position at five points in the study room with only daylighting available. This illumination level will be known as Sunlight illumination in the rest of the study [Figure 1].

Study room illumination = 130 Lux (12.08 Fc)

Sunlight illumination = 1440 lux (130.78 Fc)

The last illumination level was taken in the Hall room when there

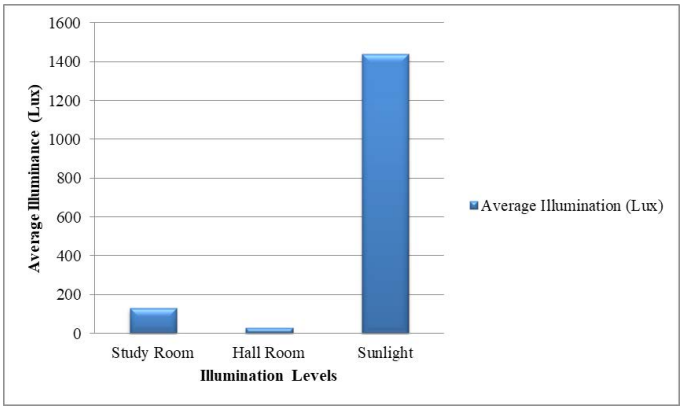

Figure 1: Illuminance Levels for the various rooms.

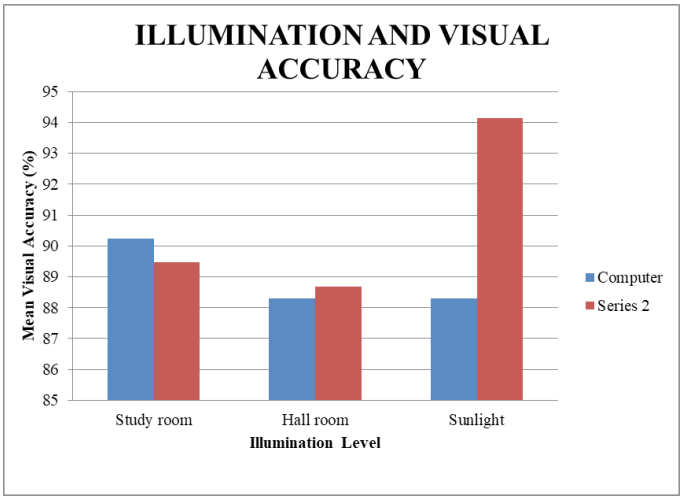

Figure 2: A plot of illumination levels against mean visual accuracy.

was only electrical illumination available. The illuminance at desk level was taken 3 different levels. The average illuminance in the hall room with only electrical illumination available was 30 lux (2.79 Fc) [Figure 2].

At all illumination levels, all participants were able to read the 0.00 log MAR optotype [Table 1]. Thus legibility at all testing at all illumination levels was 100%. Therefore the chosen illumination levels did not affect legibility or visibility of the participants.

The effect of illumination on accuracy was not significant for the computer display. Mauchly's Test of Sphericity indicated that the assumption of sphericity was not violated, χ^2 (2) = 2.669, p = 0.263 [Table 2]. Therefore the result for analysis of variance for illumination on accuracy with computer display was not significant, F (2 48) = 1.038, p = 0.362. These results suggest that visual accuracy on a computer was not affected significantly in the various illumination levels [Table 3].

However the effect of illumination on visual accuracy for the paper display was significant [Figure 3]. Mauchly's Test of Sphericity indicated that the assumption of sphericity was not violated, χ^2 (2) = 3.248, p = 0.197. Therefore the result for analysis of variance for the effect of illumination on accuracy with paper display was significant, F (2, 48) = 5.199, p = 0.009 [Table 4]. These results suggest that visual accuracy on paper was affected by the illumination levels. In fact visual accuracy with paper display significantly increased with increasing illumination

Table 1: Means and standard deviations of searching time and correct percentage under each level of the independent variables.

Independent Variables	Search Times (s)				Visual Accuracy – Correct Percentage (%)			
	Computer Screen		Paper		Computer Screen		Paper	
	Mean	*Standard Deviation*	*Mean*	*Standard Deviation*	*Mean*	*Standard Deviation*	*Mean*	*Standard Deviation*
Study Room Illumination	150.56	32.780	159.12	32.427	90.2424	6.05601	89.4624	7.10021
Hall Room Illumination	152.52	41.644	172.80	34.729	88.2916	6.67859	88.6820	8.73393
Sunlight Illumination	169.60	27.197	154.60	17.299	88.2916	5.97305	94.1440	3.37803

Table 2: Mauchly's test of Sphericity for Effect of Illumination on Computer Display.

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
computer	.890	2.669	2	.263	.901	.970	.500

Table 3: Tests of within Subjects for Effect of Illumination on Computer Display.

Source		Type III Sum of Squares	df	F	Sig.	Partial Eta Squared
Computer	Sphericity Assumed	63.427	2	1.038	.362	.041
	Greenhouse-Geisser	63.427	1.803	1.038	.356	.041
	Huynh-Feldt	63.427	1.940	1.038	.360	.041
Error (Computer)	Sphericity Assumed	1466.812	48			
	Greenhouse-Geisser	1466.812	43.261			
	Huynh-Feldt	1466.812	46.560			

Table 4: Paired Samples Statistics for Display types on Visual Accuracy.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Visual Accuracy for Computer at different Illumination levels	88.9093	225	6.13506	0.409
	Visual Accuracy for Paper at different illumination levels	90.7628	225	7.08765	0.47251

Table 5: Mauchly's test of Sphericity for Effect of Illumination on Search Time on Paper Display.

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Paper	.909	2.187	2	.335	.917	.989	.500

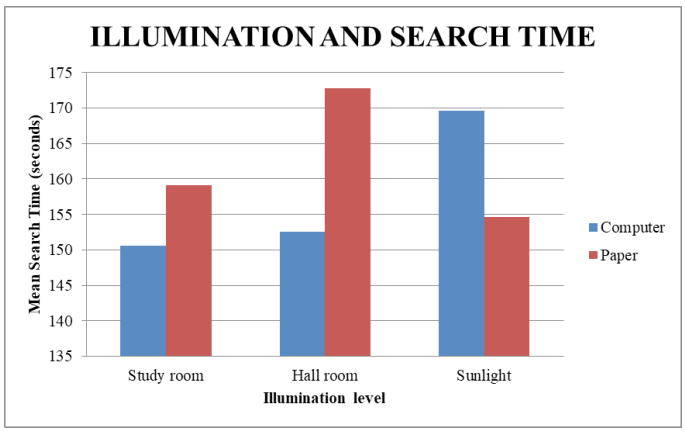

Figure 3: Illumination level against mean search time search time.

Therefore the result for analysis of variance for the effect of illumination on accuracy with paper display was significant, F (2, 48) = 4.244, p = 0.02 [Figure 4]. These results suggest that the visual search time with paper was affected by the illumination levels. In fact visual search time with paper display decreased significantly with increasing illumination.

Visual Discomfort

The effect of illumination on visual discomfort was not significant

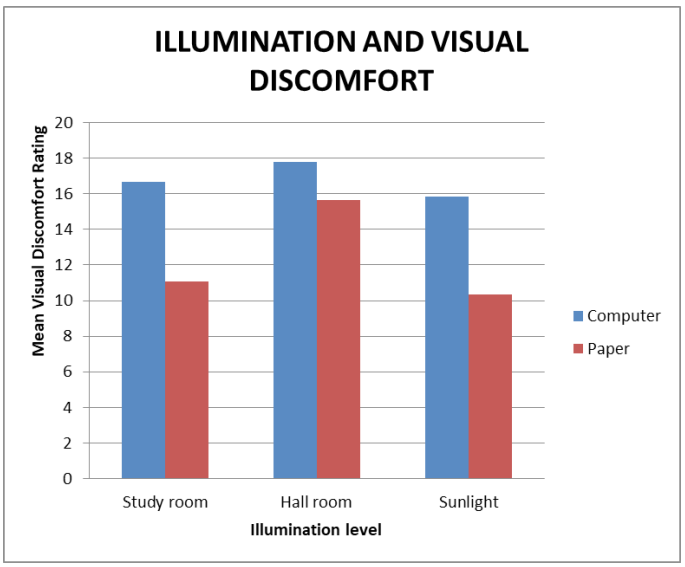

Figure 4: A plot of illumination level against mean visual discomfort rating.

for the computer display [Table 5]. Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated, χ^2 (2) = 25.222, p < 0.05.

Conclusion

The study found the effect of illumination on visual performance comparing reading on print paper and on the LCD screen o f a laptop. Three parameters under visual performance were looked at: Legibility, Visual accuracy and search time and Visual discomfort. These parameters were looked t under three illumination levels: Study room illumination, Hall room illumination and Sunlight Illumination (still in the study room bt with only daylighting available). Average illuminance at desk level for the study room, hall room and sunlight illumination levels were 130 lux, 30 lux and 1440 lux respectively. From the results of the research the following conclusions were drawn:

All 25 participants passed the legibility testing at all illumination levels. Visual accuracy was affected by illumination especially on paper display. On paper display, visual accuracy increased with increasing illuminance levels being highest at 1440 lux illuminance. Concerning visual accuracy, participants performed better with paper display than with the LCD screen of a computer at all illumination levels particularly at 1440 lux (Sunlight Illumination).

Search time was also affected by illumination especially on paper display than on a computer LCD screen display. Generally on a paper display, search time decreased with increasing illumination. However participants were generally faster on the LCD screen of a computer than on a paper display in this study across the various illumination levels.

Participants were more comfortable reading from a paper across the various illumination levels. Participants experienced more visual discomfort with computer display especially at 130 lux and 1440 lux illuminance levels.

Thus we see a higher visual accuracy with paper display even at the lowest illuminance of 30 lux, a lower visual discomfort rating indicative of increased comfort with paper than on a computer screen even at the lowest illuminance of 30 lux and an increased visual search speed which decreased significantly with increasing illuminance. Visual performance generally increased with increasing illumination on paper display than on an LCD display.

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