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Influence of Viewing Distance and Illumination on Projection Screen Visual Performance

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ABSTRACT

Projectors and projection screens have become basic and indispensable teaching aids in modern societies, and in particular, tertiary institutions. This study sought to investigate the effect of viewing distance and illumination on visual performance whilst working from a projection screen. The study, which was conducted in two lecture rooms, involved 60 participants who engaged in two different visual tasks: a proofreading task and a film-watching task. The identification rate (IR) and attention rate (AR) for the proofreading and film-watching task were collected respectively. Viewing distances of 3 m, 6 m and 9 m and illumination of 300 lux (low) and 1600 lux (high) were the independent variables. Statistical Package for Social Sciences version 23 was used to analyse the data and the level of significance was set at a p-value of 5%. The effect of illumination on proofreading performance ($p = 0.026$) and on film-watching performance ($p = 0.004$) was of statistical significance. Mean statistics showed that viewing distance affected the visual performance, with mean identification rate being inversely proportional to viewing distance and illumination. Mean attention rate peaked at 6m and was also optimum in low illumination. However, there was no significant effect of viewing distance on proofreading performance ($p = 0.684$) and film-watching performance ($p = 0.370$). Thus, to attain maximum visual performance whilst using projection screens, illumination must be considered.

KEYWORDS

Viewing Distance; Illumination; Projection Screen; Visual Performance.

ABBREVIATIONS

ANOVA: Analysis of Variance; AR: Attention Rate; CRT: Cathode Ray Tube; IR: Identification Rate; SPSS: Statistical Package for Social Scientists; TFT-LCD: Thin Film Transistor Liquid Crystal Display; VA: Visual Acuity; VDTs: Visual Display Terminals.

INTRODUCTION

Visual and non-visual variables constitute a successful task performance and consequently an increased efficiency and worker productivity [1]. A visual process includes a combination of visual acuity, peripheral awareness, depth perception, tracking ability, focus ability from near to far, convergence and divergence with ease and visual perception. The ability of the visual system to do these quickly and accurately with no discomfort can be termed as visual performance [2].

Common symptoms that indicate visual performance problems include discomfort from eyestrain, visually induced headaches, poor concentration when doing visual tasks, double or blurred vision, clumsiness and reading errors such as reversals. Different visual skills are required when carrying out different visual tasks. Visual performance is affected by factors such as the size of task, viewing distance, illumination, glare, time available to view task, movement of the task and atmospheric conditions.

It is also influenced by the visual capability of the individual, the visibility of the task and psychological and general physiological factors such as motivation, intelligence and general health [3]. The visual capability is mainly dependent on the visual system of an individual. The ability of the visual system to see details is influenced by luminance, contrast, spectral nature of light, size and intensity of surrounding field, region of retina stimulated, distance and size of object, time available to see object, refractive error, pupil size and glare [3].

There is little change in visual performance when majority of these factors are kept constant at a certain value. However, a low value or fluctuation in constancy of any of the factors results in a significant deterioration of visual performance. Visual performance can be measured by certain parameters such as speed, accuracy, search time, visibility and discomfort or fatigue [1].

Viewing distance is the distance between a point of focus and an observer. The distance affects the retinal image size [3]. Studies have shown that the closer a viewer is to his object of focus, the larger or bigger the object appears [4, 5]. Working distances may be classified as far, intermediate-to-near and very near [6]. Far distances are considered to be greater than two metres (> 2 m) while intermediate-to-near distances are between two metres and thirty centimetres (≤ 2 m ≥ 30 cm) and very near distances are less than thirty centimetres (< 30 cm).

Lighting must be planned to provide the appropriate visual conditions that will aid the efficient and comfortable performance of visual tasks [3]. There are different aspects of a lighting condition such as, illuminance, spectrum, luminance distribution, colour characteristics of light in space, uniformity of light in space, which may affect its quality.

Illumination is the visibility of objects in an area in the presence of a light source. The standard unit of measurement of illumination is lux (the illuminance produced on a surface area of $1m^2$ by a luminous flux of 1 lumen (lm) uniformly distributed over that surface (lux = 1 lm * m^{-2} or lux = lm/m2)) or footcandle (fc = lm/ft2) [7].

Digital projectors have become a key teaching aid and are used widely in many universities and other educational settings, sometimes connected to a whiteboard to interactively teach students [5]. The use of the digital projectors enhances the learning experience for students especially those who are visual learners [8]. It also helps teachers to keep their students' attention more effectively. Projectors facilitate all staff and student meetings among lecturers and students.

The purpose of this study was to investigate via the use of projection screen, the influence of viewing distance and illumination on visual performance.

MATERIALS AND METHOD

Recruitment of Study Participants

The Department of Optometry and Visual Sciences of the Kwame Nkrumah University of Science and Technology in Kumasi, Ghana, was the site where the study was conducted.

Random sampling technique was adapted in selecting 60 participants from the department for this study.

Students with VA or best-corrected VA of 6/6 were included in the study. Students with ocular conditions such as allergic conjunctivitis, uncorrected refractive errors, ocular deviations, dry eyes, retinal problems and other significant ocular morbidities were excluded from this study.

Data Collection Procedures

The independent variables in the study were viewing distance and illumination. Viewing distances of 3 m, 6 m and 9 metres were measured from the centre of the projection screen to the subject's eyes with a measuring tape. Ten seats were arranged for each distance. Participants were not allowed to move their seats in order to maintain constant viewing distances. Two lecture rooms with different illumination levels were used. The two rooms were randomly labelled as Room One and Room Two. Room One had a higher room illumination than Room Two. Participants were randomly divided into three groups labelled A, B and C, and subsequently were assigned to viewing distances of 3 m, 6 m and 9 m respectively. Every subject performed the test in the two rooms with different illumination levels.

An illuminometer (Digital lux meter LX1010B) was used to measure the illumination at desk level at 5 different points in both Room One and Room Two. The average illumination was taken as the level of illumination in each room.

Room One had an average illumination of 1600 lux. The digital projector (EPSON-78 WXGA), a ceiling-mounted projector, was permanently fixed at a distance of 25 cm from the ceiling and 267 cm from the ground.

Each experimental test lasted for twenty-two minutes and contained two different visual tasks that were performed with the projection screen: a ten-minute proofreading task and a twelve-minute film-watching task. A Compaq dual-core laptop computer was used to project the visual tasks unto the projection screen.

Proofreading Task

Ten pages of English text were projected consecutively one after the other for one minute each on the projection screen. Each page was designed to have a left and a right region with about the same text but the right region had ten errors within the text. The words per region were arranged in eight lines with an average of seven words per line task. Participants were to identify as many errors as they could within the texts that were projected on the projection screen and note them down on answer sheets that were provided. The entire proofreading task lasted ten minutes. The dependent variable, proofreading performance was collected at the end of the experiment.

Proofreading Performance

This was based on the identification rate of participants. The identification rate was defined as the ratio of the number of correctly identified errors to the total number of errors in the proofreading task.

Film-watching Task

The film-watching task immediately followed the proofreading task and also lasted for twelve minutes. Participants were made to watch a film for ten minutes after which they answered questions about the film within two minutes on answer sheets provided. Ten questions were projected on the screen and were aimed at testing the attention of participants. Meaningful excerpts of selected television series episodes were projected for ten minutes. The dependent variable, film-watching performance was collected at the end of the test.

Film-watching Performance

This was taken based on participants' attention rate, which was defined as the ratio of the number of correctly answered questions to the total number of questions in the test.

Ethical Consideration

Study participants consented willingly to partake of the study after the entire study and its procedures were explained to them. The study protocol was in conformity with the principles of the Declaration of Helsinki [9].

Data Analysis

Statistical Package for Social Scientist (SPSS) software version 23.0 was used to analyse the collected data. An independent (unpaired) t-test was conducted to determine if the three different subject groups had any effect on the results. Consequently, the mixed-factor analysis of variance (ANOVA) test was used to determine the effects of viewing distance and illumination on the performance data. The level of significance was set at $p \leq 0.05$. Effects were considered 'significant' when $p \leq 0.05$.

RESULTS

Demographic Characteristics of Study Participants

A total of 60 participants (comprising 30 males and 30 females) volunteered to participate in this study. The mean age was 20.23 ± 1.798 years. All study participants had best corrected vision of 6/6. The participants' demographics have been summarized (in Table 1) below.

Table 1: Demographic Characteristics of Participants.

Age (years)	n (Male)	n (Female)	n (Total)
18	4	4	8
19	6	10	16
20	6	4	10
21	4	4	8
22	4	2	6
23	2	4	6
24	4	2	6
	30	30	60

Where n = number of participants.

Average Illumination

The average illumination measured in room one was 1600 lux (as depicted in Table 2 below) while the average illumination found in room two was 300 lux. The source of illumination in the room was daylight. Measurements were taken during the day between 11:30 am – 12:00 noon.

Table 2: Average Illumination.

Room	Illumination (lux)					Total (lux)	Average (lux)
One	220	270	350	310	350	1500	300
Two	1400	1500	1900	1700	1500	8000	1600

Independent t-test

An independent t-test was carried out to determine if the different subject groups (between – subjects factor) would have a significant effect on the visual performance. The results showed that the different subject groups did not have any effect on the identification and attention rates as illustrated (in Table 3) below. This confirmed that using different subjects with best corrected VA and with no ocular disease or abnormality posed no interference with the results of the experiment.

Table 3: Independent t-test.

Group	Dependent variable	t	Df	p value
A and B	IR	0.142	38	0.888
	AR	-1.089	38	0.283
A and C	IR	0.75	38	0.458
	AR	0.371	38	0.713
B and C	IR	0.643	38	0.524
	AR	1.292	38	0.204

Where: IR= Identification rate; AR= Attention rate; df= degree of freedom; p= level of significance.

Visual Performance in Different Illumination

The mean statistics showed that identification rate during the proofreading task increased from 79.6% in high illumination to 84.1% in low illumination. The attention rate also increased during the film-watching task from 64.3% in high illumination to 72.3% in low illumination as shown (in Table 4) below. Illumination was found to have a significant effect on the proofreading performance irrespective of the viewing distance. Thus, $F (2, 57) = 5.210$ and $p = 0.026$ as indicated (in Table 5) below. However, there was no significant interaction effect of viewing distance and illumination on the proofreading performance. Thus $F (2, 57) = 0.440$ and $p = 0.646$ as indicated (in Table 5) below. Illumination significantly affected film-watching performance [$F (2, 57) = 8.755$ and $p = 0.004$ also (in Table 5) below]. The interaction effect of viewing distance and illumination on the film-watching task was, however, insignificant [$F (2, 57) = 0.866$ and $p = 0.426$].

Table 4: Mean Visual Performance in Different Illumination.

Illumination (lux)	n	Identification rate (%)	Attention rate (%)
High	60	79.6 ± 20.0	64.3 ± 13.5
Low	60	84.1 ± 8.6	72.3 ± 18.9

Table 5: Mixed-factor ANOVA Results of Independent Variables on Visual Performance.

Independent	Proofreading performance			Film-watching performance		
variable	df	F	p-value	df	F	p-value
Illumination	(2, 57)	5.21	0.026	(2, 57)	8.755	0.004
Viewing distance	(2, 57)	0.382	0.684	(2, 57)	1.012	0.37
Illumination and viewing distance	(2, 57)	0.44	0.646	(2, 57)	0.646	0.426

Where: df= degree of freedom; F=F test statistic and p= level of significance.

Visual Performance at Varying Viewing Distances in High Illumination

The mean statistics showed identification rates of the proofreading task in high illumination to be 81.1%, 81.4% and 76.2% for the viewing distances 3 m, 6 m and 9 m respectively as illustrated (in Table 6) below. The attention rates of the film-watching task in high illumination were 66%, 66% and 61% for the viewing distances 3 m, 6 m and 9 m respectively. Similar identification and attention rates were recorded between the 3 m and 6 m groups but these rates were lower in the 9 m group.

Table 6: Visual Performance at Varying Viewing Distances in High Illumination.

Viewing distance (m)	n	Identification rate (%)	Attention rate (%)
3	20	81.1 ± 18.0	66 ± 10.5
6	20	81.4 ± 13.2	66 ± 11.4
9	20	76.2 ± 26.9	61 ± 17.4

Where: n= number of participants.

Visual Performance at Varying Viewing Distances in Low Illumination

From the results of the mean statistics, identification rates of the proofreading task in low illumination were 85.2%, 83.9% and 83.2% for the viewing distances 3 m, 6 m and 9 m respectively as shown in (Table 7) below. There was a marginal decrease in identification rate with increasing viewing distance. However, similar identification rate was recorded between the 6 m and 9 m groups. The attention rate of the film-watching task was optimum at 6 m.

Table 7: Visual Performance at Varying Viewing Distances under Low Illumination.

Viewing distance (m)	N	Identification rate (%)	Attention rate (%)
3	20	85.2 ± 6.2	69 ± 17.4
6	20	83.9 ± 10.3	77 ± 16.6
9	20	83.2 ± 9.1	71 ± 22.2

Where: n= number of participants.

DISCUSSION

This study investigated the effects of viewing distance and illumination on projection screen visual performance. Visual performance was evaluated on the basis of a proofreading performance (as measured by IR) and a film-watching performance (as measured by AR), which were the outcomes of a proofreading task and a film-watching task respectively.

Proofreading Performance

The outcome of the proofreading task showed that the average performance decreased slightly with increasing viewing distance. A marginal decrease in the identification rate was observed as the viewing distance was increased. This similar trend is reported in previous studies [5]. Thus, viewing distance has an effect on the legibility of words [4].

For an object of a particular size, the viewing distance can alter the size at which it is perceived. This is because viewing an object at a particular distance subtends at an angle on the retina. This angle, referred to as visual angle, increases with shorter viewing distance and decreases with longer viewing distances.

A larger visual angle of text results in a good reading comprehension performance [10] but poor proofreading performance with increasing viewing distance was as a result of the reduced visual angle corresponding with the increasing viewing distance [5]. Therefore, the ability to distinguish the separation between two objects (detail discrimination) or to be able to read any text displayed is as a result of distance and not the visual area stimulated. [11].

However, in this study, though the mean statistics showed that viewing distance affected proofreading performance, mixed-factor ANOVA revealed that there was no significant effect of viewing distance on the identification rate ($p = 0.684$). The viewing distances may have been insufficient to cause any significant differences in the participants' visual performance. Visual performance and visual fatigue were assessed under different viewing distances but at a constant viewing angle [12]. It was found that viewing distance had no significant effect on visual performance and visual fatigue.

Visual angle is much influenced by letter size than object distance as reported in previous studies [13]. It can therefore be inferred that the outcome of viewing distance on visual performance in this present study may have occurred as a result of an almost constant visual angle at the different viewing distances. The comfortable and good vision of participants may account for the insignificant effect of viewing distance on the visual performance.

A significant effect of illumination on identification rate was observed in the present study (p = 0.026). Mean visual performance increased considerably in low illumination (300 lux) as compared to high illumination (1600 lux). High illumination reduces the contrast between objects and texts of focus and their background, thereby decreasing their legibility [14]. Moreover, high illumination can wash out texts and images on the screen and perhaps cause glare that can interfere with visual tasks. The washing out effect can result in eyestrain and cognitive strain in trying to make meaning of the faint appearance of objects on the part of the observer.

Low illumination can reduce the blotting out of messages or information on screens and displays and improve legibility. Illumination can be low but not to the extent where it makes performing visual tasks difficult [15]. Furthermore, reflections from the projection screen or the walls behind or around the screen in high illumination can cause disability glare and make it difficult to see the information projected on it. This can account for poor visual performance in high illumination as was observed in this study. The finding of optimum performance in low illumination (300 lux) in this study is consistent with findings of previous studies on VDTs and CRTS [16, 17]. An illumination of 150-500 lux is thus ideal for CRT work [18] while an illumination of 450 lux is considered suitable for TFT-LCD work [17].

Film-watching Performance

The result of the film-watching task revealed that attention rate decreased as viewing distance was increased from 3 m to 9 m and from 6 m to 9 m in both high and low illumination. However, in low illumination, best film-watching performance was recorded at 6 m.

Sitting too close to a large screen on which images are sharply focused results in having an enlarged retinal image and consequently a large field of view [19]. The size of one's field of view affects the quantity of details that can be captured by the eye. A large field of view results in having a smaller portion of detail of an object in view and missing out on the details if the object is a moving one (like is seen in a video). Inferring from the theory of magnification, a large field of view brings a small part of the object into view. The object becomes much magnified that in reality, a small portion of the object is actually being viewed at a time. A person will have to move his eye constantly to capture the entire details of an object in motion. This can result in eye fatigue and consequently a loss of interest in the object of focus. This may account for the poor performance at 3 m.

Being farther away from an object can also reduce the clarity of information that can be processed and perceived. Similar to the proofreading performance, reduced visual angle may account for the poor attention rate at 9 m. Though the mean statistics in this present study showed a difference in visual performance at the different viewing distances, this difference was not statistically significant. These findings are consistent with previous studies in which no significant effect of viewing distance on attention rate was reported, though a slight reduction in the mean attention rate as a result of increasing viewing distance was recorded [5].

Bright illumination during the film-show tends to reduce the quality of the pictures as the colors of the pictures blend with the illumination in the room and there is reduced contrast [15]. Consistent with this finding, an illumination of 300-500 lux is considered ideal for optimum visual performance [20]. A low illumination of 200 lux was not only subjectively preferred, but was better for visual recognition than in illumination of 700 lux [16]. While some studies showed that illumination was not a significant factor for visual performance [21-23], this study revealed that low illumination of 300 lux produced a good mean visual performance as compared to a high illumination of 1600 lux.

CONCLUSION

The use of projectors and projection screens as teaching aids have become very common in our modern society and is being employed by many tertiary institutions to make lessons more interactive and engaging. It is worth stating, however, that visual performance can be influenced by a number of factors. The present study considered the factors, viewing distance and illumination vis-à-vis visual performance while working from a projection screen. This study found that illumination had a significant effect on both identification and attention rates while viewing distance had no significant effect. Illumination of 300 lux will be more appropriate for visual tasks that include both texts and images. However, illumination as high as 1600 lux is inappropriate for carrying out visual tasks because it reduces visual performance. Thus, to attain maximum visual performance whilst using projection screens, illumination must be taken into consideration.

DECLARATION

The authors declare that this work stems from an original research that was conducted, and this work has not been submitted or published elsewhere with other publishers.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest as far as the publication of this manuscript is concerned.

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