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EFFECT OF ENERGY EFFICIENT LIGHT SOURCES ON READABILITY OF STUDENTS – AN EXPERIMENTAL APPROACH

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Abstract

The objective of this paper is to investigate the effect of light sources on readability of students using psychophysical methods. Light sources such as Compact Fluorescent Lamp (CFL) and Light Emitting Diode lamp (LED) of same power rating were used in this research work because of their high lighting efficiency and uniformity of illuminance compared to that of Incandescent lamp (IL) and florescent lamp (FL). A group of prospective students having normal vision, and abnormal vision like myopia, hypermetropia and astigmatism were involved in the test process. Three types of test like Snellen visual acuity, Color contrast test and Readability test were conducted on student participants under different lighting conditions. Test results showed the visibility and color contrast sensitivity of the students were high in the LED illumination. The quantitative measure of readability under different circumstances showed that the lightness difference on text under different color combination and font size, affected their readability. The computed average results confirmed that the luminance and color contrast were improved in LED illumination and also proved a high readability measure in the experimentation. Both the results of psychophysical test were proven that LED lighting was the best lighting system suitable for color distinction and readability

Keywords: Readability, Color contrast, Luminance contrast, Psychophysics, Visual performance

1. Introduction

Reading text is one of the vital visual activities that every student makes regularly. Such textual information should be clearly visible, legible to read and ease of reading. This could be possible only with good lighting conditions provided by artificial light sources having characteristics close to natural lighting

Abbreviations

CCT	Correlated Color Temperature
CFL	Compact Fluorescent Lamp
CRI	Color Rendering Index
FL	Fluorescent Lamp
IL	Incandescent Lamp
LED	Light Emitting Diode
LOR	Light Output Ratio

(sun). Readability is an important measure to access the visual performance of human beings. It is defined as the ability to read the sentences easily irrespective of their meaning of the stimulus material that could be from any form of sources. There are many factors that affect the visual performance and readability. In the past, many psychophysical methods have been used in the laboratory to examine the visual factors in reading. Those research methods aimed at understanding the role of sensors used, perceptual mechanisms involved and effect of visual impairments in reading. They used reading rates (speed of reading) as the key factor of determination in almost all the research works.

Usually, text information can be depicted by two factors, namely the brightness contrast and the color contrast. The brightness (luminance) contrast is the difference in luminance between the dark text characters and white background, whereas the color contrast is the differences in chromaticity. Reading rates have been proved to be the highest in the case of black letters on white background (luminance contrast) whereas slightly low in colored text on a colored background (color contrast). Readability was measured for 11 combinations of colored text printed on colored background and observed high reading speed on high brightness contrast samples. The rate of reading was measured as a function of luminance and color contrast [1]. A comparative analysis of luminance and color contrast using the psychophysical method of reading proved that luminance contrast offered best reading compared to color contrast. People with normal vision can read rapidly as the color and luminance contrast increases, but there was no effect on people with low vision for high color contrast [2].

Moreover the light sources also played a vital role in readability. Research work had found that artificial light sources affect the human beings, both physiologically and psychologically [3]. Such light sources had produced a great impact on visual performance which was varied with respect to the age of the person, intensity of illumination and color of the source [4]. Particularly the working speed of the people, accuracy of observation and completing the task performance was found to be higher under artificial illumination [5]. Light sources with high color rendering index and high color temperature provided better readability and perception in older adults [6, 7]. High luminance contrasts between foreground and background colors enhanced the legibility of text which was another important requirement for rapid reading [8]. Further, there was an influence of luminance polarity on reading and performance of optimized color combinations [9]. There was also an effect of the screen type used, ambient illumination and color combinations on the visual display terminals that affects the visual performance [10]. Then a different method of extracting a target word from a newspaper was used as a measure of readability [11]. To determine the

readability and contrast measurement accurately, daylight was used as a source which can be used for comparison of artificial lighting sources [12].

In recent few years market trend, LED tried to occupy in most fields and applications. Initially the LED was used for display terminals, remote control switches, etc., and nowadays it has been suggested for the indoor lighting purpose because of its brightness and less power consumption. Since the LED lamp was recommended for indoor lighting application, there was a need to test its effect on color contrast, luminance contrast and readability [13]. The Author had proved that the difference in light source (FL and LED) affected the readability of colored text that varied from young person to an older person [14]. Similarly the rate of reading was measured on the screen displays with various foreground and background color combinations along with different font types. The concentration of the students was greatly affected by the conventional lighting conditions that can be greatly improved by installing the dynamic lighting system in the classroom [15].

Based on the complete literature; it was found that many research works were done on readability and color contrast with respect to luminance variation, color correlated temperature and so on. But there was no special attention given towards a measure of readability of students with varying text font sizes, text colors and background colors under different types of illumination. Moreover, the impact of using energy efficient lamps for indoor applications also addressed in this research work. In this paper, this problem is addressed by comparing the effect of energy efficient light sources on color contrast and readability of students, attempted to prove it experimentally.

The objective of this work is to determine the best suitable lighting system for a class room that consumes less power, improves the color contrast and enhance readability of students. The experiments were based on the reading rate of students under different lighting conditions and their ability to identify the colored numbers present in the Ishihara color chart.

2. Methods

2.1. Overview

Three types of test were conducted here to determine the effect of light sources on luminance contrast, color contrast and readability. To assure the perfect visibility of the student participants, the Snellen visual acuity test was conducted under two types of illuminants. Then to check their color vision, Ishihara color blindness test was conducted. Those participants who had cleared both the test were allowed to take the readability test under two types of illuminants. Readability test was performed by all the selected participants and their speed of reading was monitored in both the illumination case. Based on the computed results of readability, the best lighting system suitable for carrying out regular reading is suggested.

2.2. Illuminant sources and test setup

There are many light sources available such as incandescent lamp, florescent lamp, compact florescent lamp and LED lamp. But the IL and FL were consuming more power and resulting in less uniformity of illuminance which was

already proved [16]. Hence the light sources that consume less power, producing high uniformity of illuminance, high lighting efficiency were considered in this experimental work. Also, the lighting condition in the task area meant for reading purpose must have at least 150 lux which is obtained from lamp having an output of around 400 lm. Accordingly CFL and LED lamps of same power rating (8W) producing light output of around 400 lm were selected for this test process. The specifications of the chosen lamps were Philips Master LED bulb D8-40W E27 2700K 230V A60 and Philips Genie 8W E27 6500K A 60 (CFL). The structures of the lamps used in this experiment are shown in Figs. 1(a) and (b). The Light output ratio (LOR) of the Philips CFL was 68%, whereas the Philips LED light was 100%. The luminous emittance curves of both the lamps representing the C0-180 and C90-270 planes are shown in Figs. 2 and 3 respectively [17]. This graph was obtained from the Philips lamp plug in module data sheet. The parameters concerned to the lamps are listed out in Table 1. The testing procedure was carried out inside a laboratory provided with a surface mounted lighting arrangement, study table and a chair. The test sheets were placed over the surface of the table and the viewing distance of observers was fixed at 25 cm from the surface. Observations were noted done for two different types of lamps fitted in the light holder one at a time during the test process.

Table 1. Parametric specifications of light sources used in this work.

Content	Philips CFL	Philips LED
Power rating	8 W	8 W
Voltage	230 V	230 V
Base	E27	E27
Frequency	50 Hz	50 Hz
CCT	2700 K	6500 K
Luminous flux	470 lm	415 lm
Luminous efficacy	59 lm/W	52 lm/W
CRI	93	80
Life time	25000 hours	15000 hours
Effect	Warm white	Cool day light
Dimmable	Yes	No

(a) **(b)**

Fig. 1. Structure of the CFL and LED lamps.

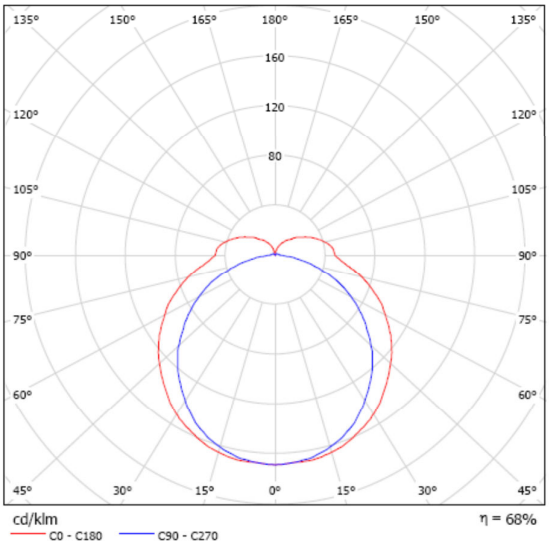

Fig. 2. Luminous emittance of CFL.

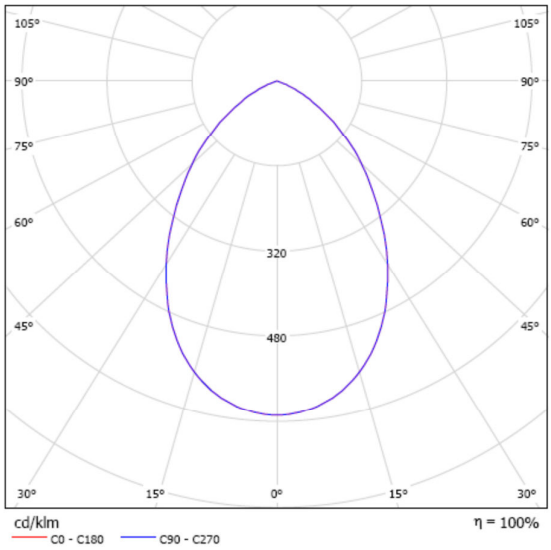

Fig. 3. Luminous emittance of LED lamp.

2.3. Snellen visual acuity test

The number of students in a class room would vary from 40-60. Here a group of 55 prospective students in the age limit of 18-21 belong to the same class room were chosen for this experiment. This sample size would be sufficient to judge the performance of students under varying lighting environments. Out of them 45 students were with normal vision and remaining 10 students with abnormal vision corrected by wearing spectacles. Initially, all the students were screened for

Snellen visual acuity test to assure their perfect visibility. This test was performed in an eye testing centre with the help of Snellen eye chart in two different types of light sources mentioned above. Test results showed that the corrected acuity of 20/20 for normal vision students and 20/40 for the students with abnormal vision. Students who passed in this test were only 44 and they were allowed to take the next test.

2.4. Color contrast test

The students were then allowed to take the color blindness test in the laboratory to determine the deficiency of certain color cones using the Ishihara color chart [18]. All the prospective students were informed about the test procedure at the beginning. This test was done in a laboratory using two types of light sources of the same power rating and average light flux of around 400 lm one at a time. First the color blindness test was conducted on the Philips (CFL) lighting condition. The experimental set up table along with a chair was placed exactly below the ceiling mounted lamp. Each student was made to sit on the chair placed next to the work table in an erected straight position. They were allowed to relax in the lighting condition for 2 minutes so as to adapt themselves in the ambient lighting condition. The distance of observation of the students was maintained vertically constant at 25 cm from the measurement table. From the Ishihara color chart, only 15 pages were selected and the students were asked to identify the colored numbers embedded inside the color dots of the Ishihara color chart. Two sample pages of the Ishihara color chart are shown in Fig. 4. The readings were monitored continuously and the number of correct identifications was recorded along with the time duration and power deficiency of the students. Again the same test procedure was performed in the Philips LED lighting condition and readings were monitored and recorded. The number of participants passed in this test was only 42 and 17 participants produced a redundant performance. Hence, the observed power deficiency, time duration, and correct identifications of only 25 participants after removing the redundant performance in CFL and LED lighting system are presented in Table 2. The complete flowchart showing the testing methodology of color contrast is presented in Fig. 5. The efficiency of identification in CFL and LED illumination is represented in Fig. 6. This test result showed that the ability of the students to identify the colored numbers in LED illumination is higher compared to CFL illumination with less time duration. This method confirmed the visual comfort and speed is good in LED illumination.

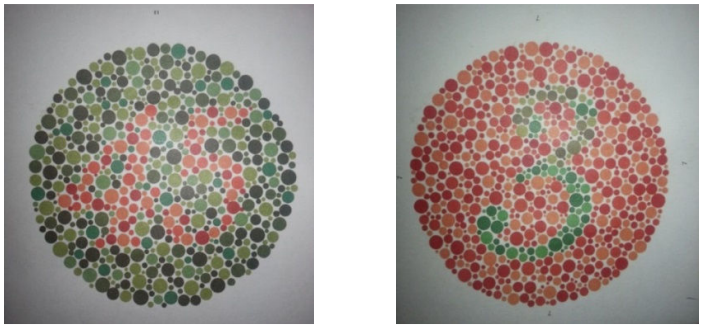

Fig.4. Sample pages of Ishihara color chart showing the colored numbers with colored background.

Table 2. Observed values of Ishihara color contrast test performed by students in LED and CFL illumination.

Students	Power Deficiency	Time (s) taken in		Corrected reading in	
		CFL	LED	CFL	LED
1	-	01:04:00	36:45	15	15
2	-3.75	44:28	27:31	13	15
3	-6.5	23:72	23:02	12	14
4	-	23:23	22:33	9	14
5	-	01:22:00	01:08:00	15	15
6	-	24:03	20:31	15	15
7	+1.25	28:19	28:11	14	14
8	-	25:47	27:01	14	15
9	-	29:04	28:01	15	15
10	-1.5	38:31	20:16	13	14
11	-4	36:47	26:53	13	15
12	-	38:27	31:30	15	15
13	-	31:21	29:04	14	14
14	+0.5	33:37	30:00	13	12
15	-	37:17	24:28	15	15
16	-	33:12	24:59	15	14
17	-	29:14	25:03	15	15
18	-2	19:10	15:25	15	15
19	-	37:29	26:32	15	15
20	-1.25	36:02	32:54	11	14
21	-	31:07	24:33	14	14
22	-1.75	28:12	26:29	14	14
23	-2.75	27:06	25:09	15	14
24	-	30:00	25:05	14	15
25	-	25:47	27:01	14	15

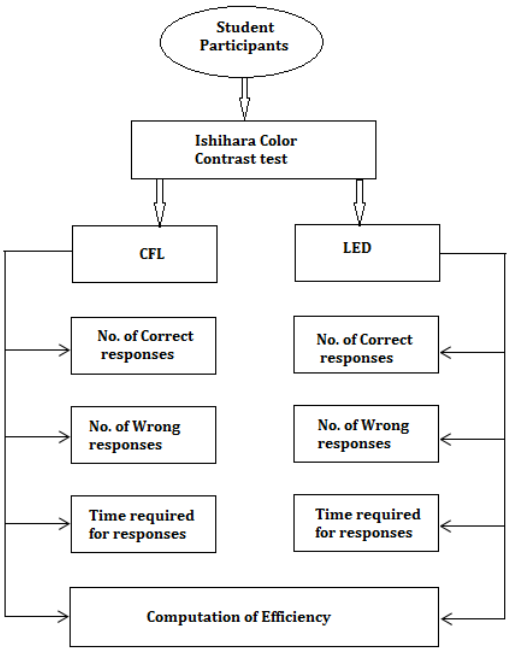

Fig. 5. Flow chart representing the Ishihara color contrast test.

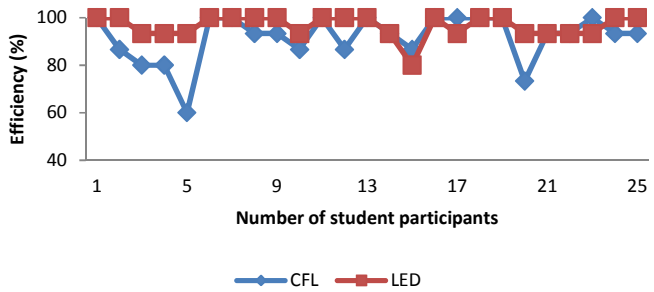

Fig. 6. Efficiency of identification in CFL and LED illumination.

2.4. Readability test

To initiate the readability test, four test samples were made on A4 size sheets. Each sheet was made with different background colors like white, orange, red and yellow. Paragraphs containing character text were printed with four different font sizes such as 10, 12, 14 and 16. The usual practice of testing luminance and color contrast, were creating samples with dark letters on bright backgrounds. In this experiment, two samples were made using dark letters on bright backgrounds and other two samples were made by dark letters on dark backgrounds. The details of the four test sample sheets are described as follows. The first sample sheet had black colored text on white background with four paragraphs containing, 75 words of 10 font sizes, 78 words of 12 font sizes, 56 words of 14 font size and 55 words of 16 font sizes. The contrast ratio of black text on white background resulted in 21:1. The second sample sheet had red colored text on orange colored background resulted in a color contrast ratio of 2:1. This sheet was with four paragraphs of 63 words 10 font sizes, 71 words 12 font sizes, 65 words 14 font size and 61 words 16 font sizes. The third sample sheet had blue colored text on red colored background with a contrast ratio of 2.1:1. This sample sheet had four paragraphs containing, 50 words of 10 font sizes, 64 words of 12 font sizes, 58 words of 14 font size and 70 words of 16 font sizes. Fourth sample had blue colored text on yellow colored background with four paragraphs containing, 57 words of 10 font sizes, 57 words of 12 font sizes, 62 words of 14 font size and 71 words of 16 font sizes. The contrast ratio of blue text on yellow background resulted in 8:1. The images of the sample sheets are presented in Appendix (A).

Reading test was performed again in the same laboratory with the help of ceiling mounted CFL lamp and sample test sheets. The methodology of executing the test process is shown as a flowchart in Fig. 7. The viewing distance of the participants was made constant to avoid errors in the observation. All the student participants were gathered inside the laboratory and informed about the test procedure. As a first step, readability test was performed under the CFL lighting condition. Each student was asked to read aloud the contents available on the four test sample sheets one by one. Times taken by each participant for reading each and every paragraph with different font sizes were measured independently. After all the participants had completed the test under CFL source, LED lamp was

replaced in the luminaire set up. Again the entire procedure was repeated by all the participants and timings were noted down. The times taken by students to read the test sample sheets under CFL and LED illumination are shown in Figs. 8 (a – d) and 9 (a-d).

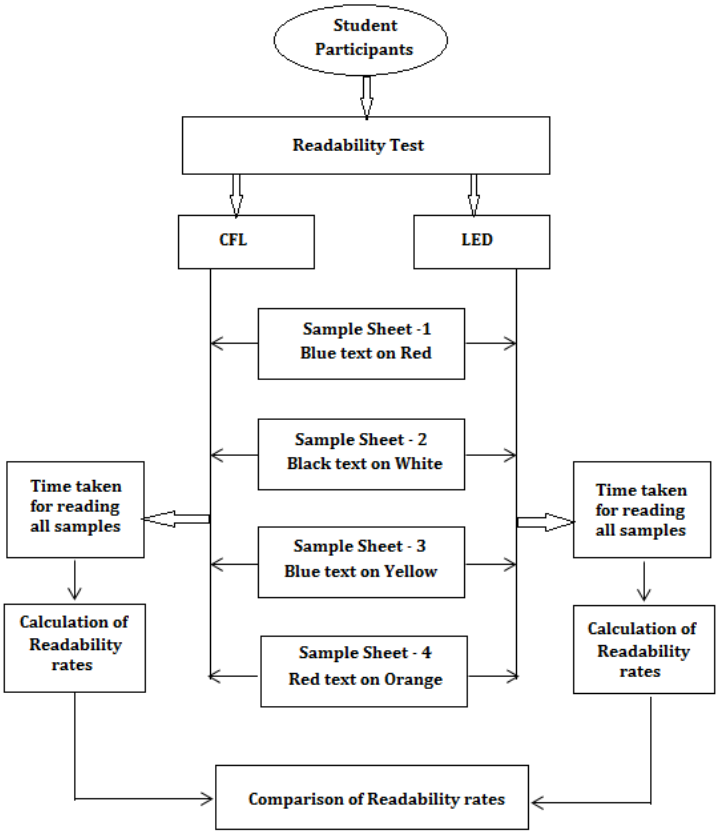

Fig. 7. Flow chart representing the readability test.

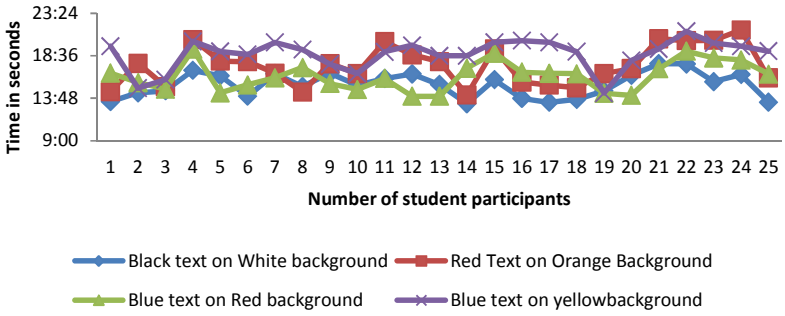

Fig. 8(a). Time taken by 25 student observers to read 10 font sizes paragraph in four colored sample sheets under CFL illumination.

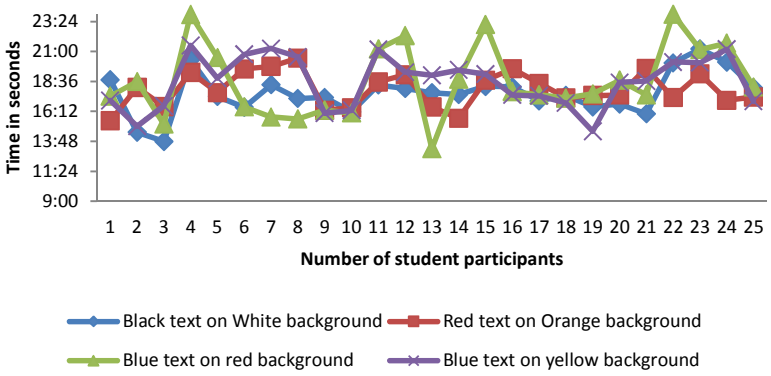

Fig. 8(b). Time taken by 25 student observers to read 12 font sizes paragraph in four colored sample sheets under CFL illumination.

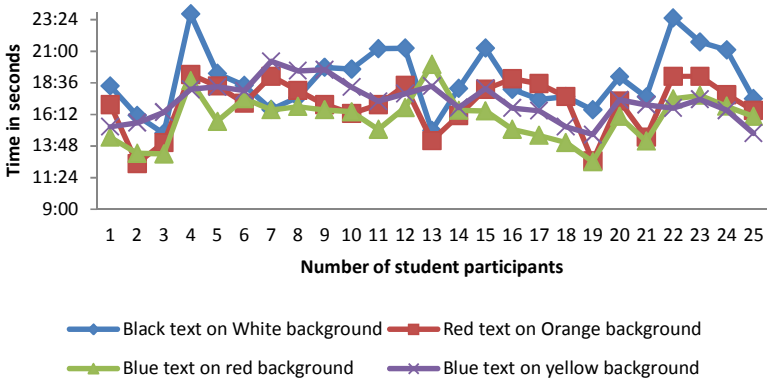

Fig. 8(c). Time taken by 25 student observers to read 14 font sizes paragraph in four colored sample sheets under CFL illumination.

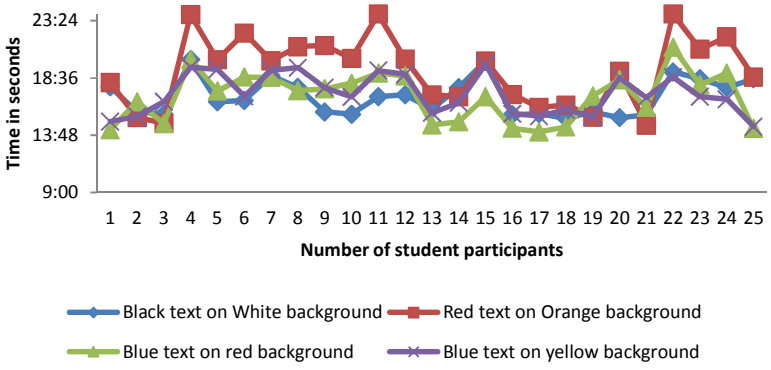

Fig. 8(d). Time taken by 25 student observers to read 16 font sizes paragraph in four colored sample sheets under CFL illumination.

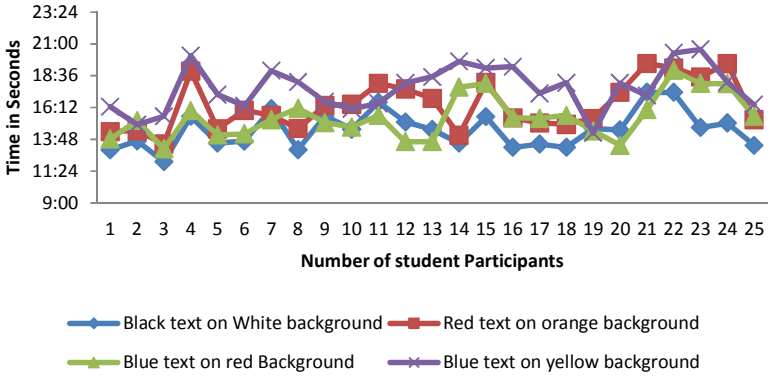

Fig.9(a).Time taken by 25 student observers to read 10 font sizes paragraph in four colored sample sheets under LED illumination.

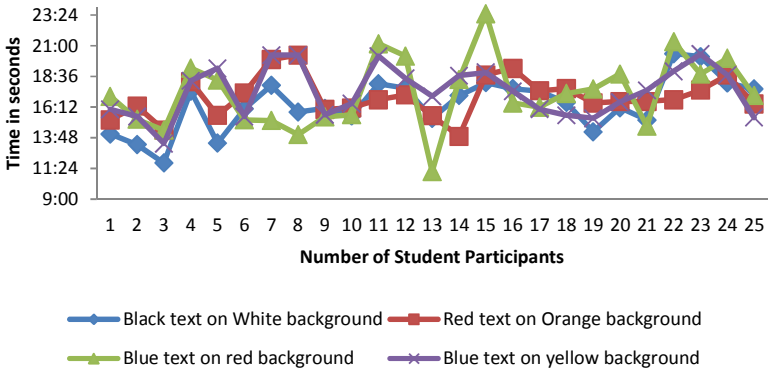

Fig.9(b). Time taken by 25 student observers to read 12 font size paragraphs in four colored sample sheets under LED illumination.

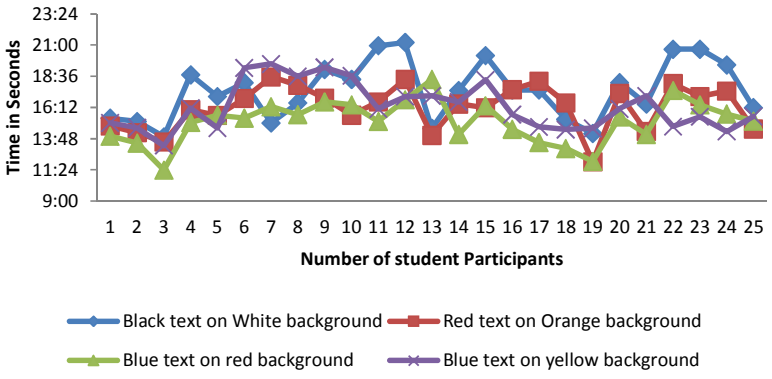

Fig. 9(c). Time taken by 25 student observers to read 14 font sizes paragraph in four colored sample sheets under LED illumination.

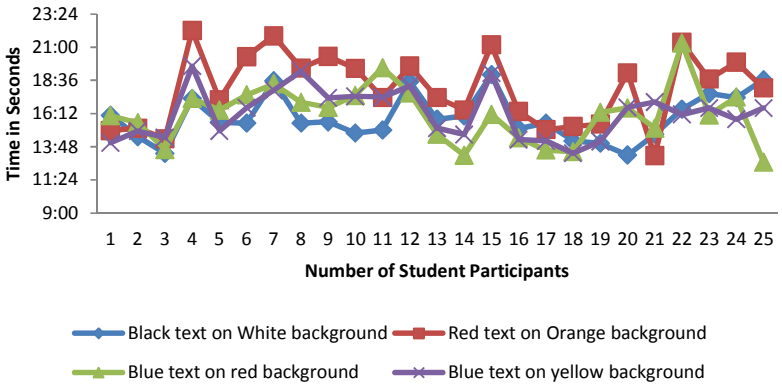

Fig. 9(d). Time taken by 25 student observers to read 16 font sizes paragraph in four colored sample sheets under LED illumination.

3. Performance Evaluation

The goal of this method to determine the rate of readability is computed from the observed timings and number of words available in each paragraph. The amount of time taken by all the participants for reading each sample test sheet under CFL illumination is plotted in the figures 8(a)-(d). From the graph of measured timings, it was observed that the average time taken to read red colored text on orange background with paragraph of 10 font size was 15:11s, 12 font sizes was 17:26 s, 14 font sizes was 19:09s and 16 font sizes was 17:22s. For the sample sheet with black text on white background, the average time taken was computed as 17:35s for 10 font sizes, 18:09 s for 12 font sizes, 17:20 s for 14 font sizes and 19:25s for 16 font sizes. For the third sample sheet with blue text on red background, the average time taken was found to be 16:15s for 10 font, 18:57s for 12 font, 16:18s for 14 font and 17:29s for 16 font sizes. Final sample sheet with blue text on yellow background recorded the average time taken to be 19:04s for 10 font, 18:46s for 12 font, 17:03s for 14 font and 17:07 for 16 font size.

In the second trial with LED lamp, again the time taken by all the student participants to read the sample sheets were noted down and is represented in figures 9 (a)-(d). The average time taken to read the red colored text on orange background with paragraph of 10 font size was 14:36s, 12 font sizes was 16:30 s, 14 font sizes was 17:36s and 16 font sizes was 16:16s. For the sample sheet with black text on white background, the average time taken was computed as 16:22s for 10 font sizes, 17:21s for 12 font sizes, 16 s for 14 font sizes and 18:08s for 16 font sizes. For the third sample sheet with blue text on red background, the average time taken was found to be 15:34s for 10 fonts, 16:21s for 12 fonts, 15:38s for 14 fonts and 16s for 16 font sizes. Final sample sheet with blue text on yellow background recorded the average time taken to be 18:01s for 10 font, 17:27s for 12 font, 16:12s for 14 font and 16:10s for 16 font size. From the computed results of average time taken by the observers, it is found that students have taken less time for reading in LED illumination when compared with CFL illumination, irrespective of the font sizes.

The total number of words in each paragraph of all the sample sheets was counted already. Then the average time taken to read under both the types of illumination was calculated. Using the above data, the rate of readability (words/second) was calculated using Eq. (1).

$$Rate\ of\ readability = \frac{Total\ number\ of\ words}{Average\ time\ taken} \quad (1)$$

The average time taken by the students to read under two types of illuminants is presented as a graph in Fig. 10. The readability of different colored text of different font size under CFL and LED illumination is computed and represented in graph as shown in Fig. 11. In the x-axis types of illuminants and sample font sizes of the sample texts are presented whereas in the y-axis rate of readability in words/second is represented. From the graph, it is observed that the average time taken by the students to read the text under LED illumination is very less compared to the CFL illumination, irrespective of the text font sizes and background colors. The rate of readability is the measure of speed which is high in the case of LED lighting when compared to CFL. The luminance contrast of black text on white background with 10 fonts resulted in high readability of 4.62 words/second in LED illumination whereas 4.32 words/second in CFL illumination. For the same sample of 12 font sizes resulted in a readability of 4.53 words/second in LED illumination, whereas it resulted a readability of 4.31 words/second in CFL illumination. In the other case, high readability of 4.41 words/second resulted from the blue text on yellow background with 16 font sizes in LED illumination whereas 4.16 words/second in CFL illumination. In addition, blue text on red background with 16 font sizes produced readability of 4.35 words/second and 4.05 words/second in LED and CFL lighting respectively. The above listed results confirmed that the luminance and color contrast is better in LED illumination when compared to CFL of the same power rating. This better contrast of LED lighting enabled high readability of students irrespective of the font sizes. Moreover, for better reading, font size 12 is recommended as the standard font size as it was proved from the experimental result.

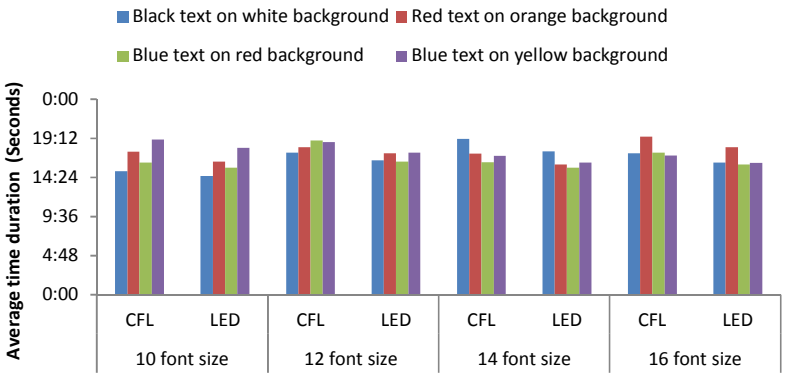

Fig. 10. Average time taken by students versus types of illuminants and text font sizes.

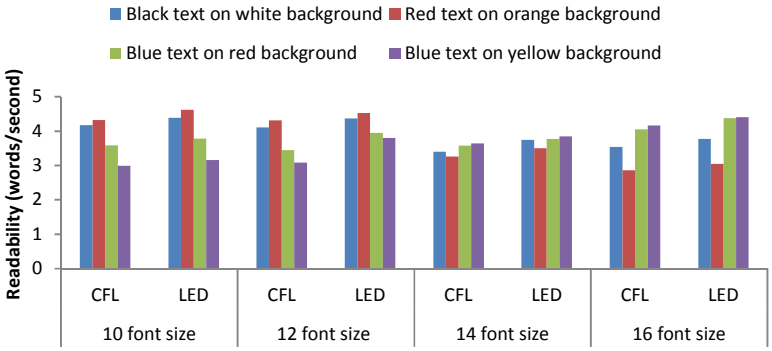

Fig. 11. Rate of readability (words/second) versus types of illuminants and text font sizes.

4. Conclusions

The best lighting system for improving the luminance contrast, color contrast and readability were determined psychophysically with the help of test samples. High color contrast capability was found using the Ishihara color chart test under CFL and LED illumination. This method proved that LED illumination had better color contrast resulting in faster identification of colored numbers in the chart compared to CFL illumination. The readability test was done using four sample color sheets with different colored text of varying font sizes under CFL and LED illumination. This test also had confirmed that LED illumination resulted in a high rate of readability irrespective of font sizes and colors compared to CFL illumination. From these cumulative results, it has been suggested that under LED illumination, students can perform their reading visual activity with high speed and accuracy irrespective of color and font sizes. Also, the energy efficient LED lamps can be used as an alternative for the existing conventional light sources employed in indoor applications.

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Appendix A

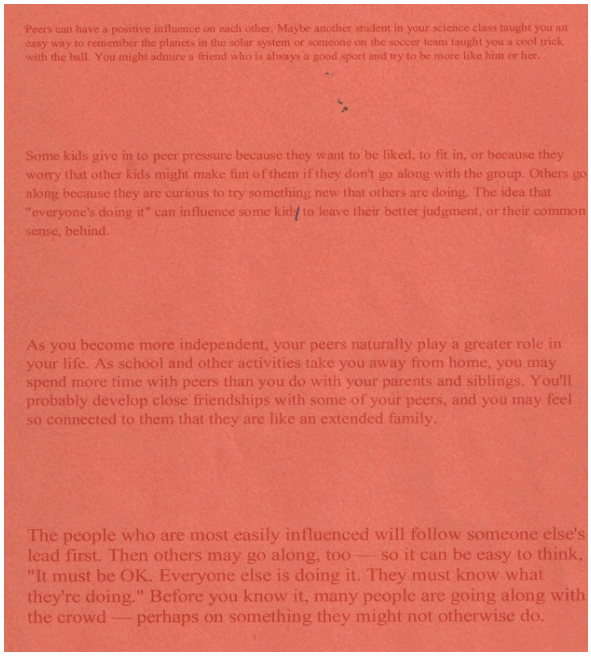

Fig. A-1. Sample test sheet-1: Red text on orange background

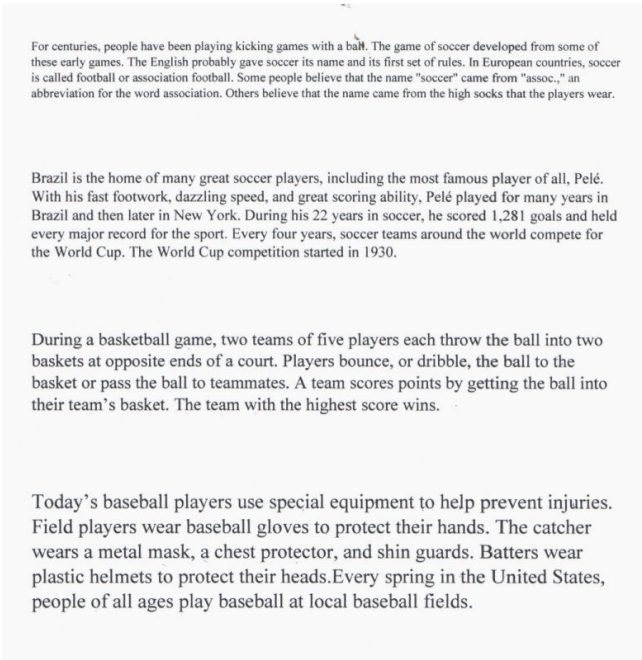

Fig. A-2. Sample test sheet-2: Black text on White background.

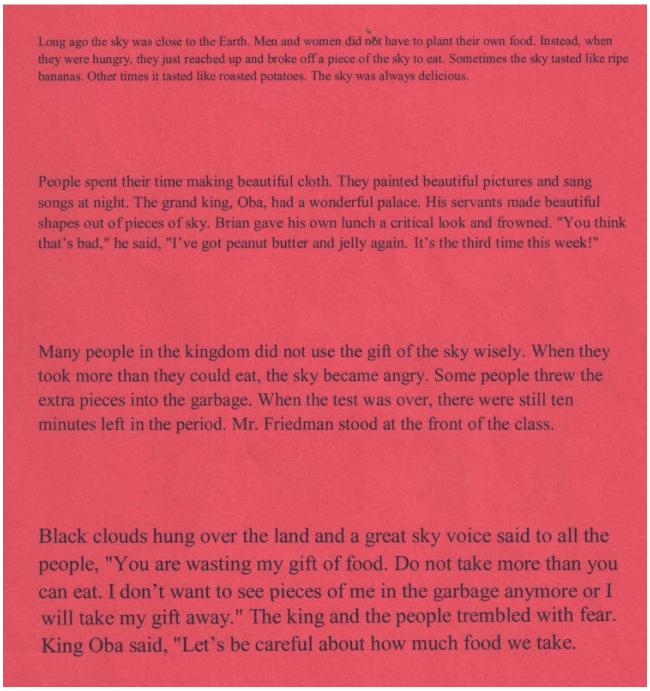

Fig. A-3. Sample test sheet-3: Blue text on red background.

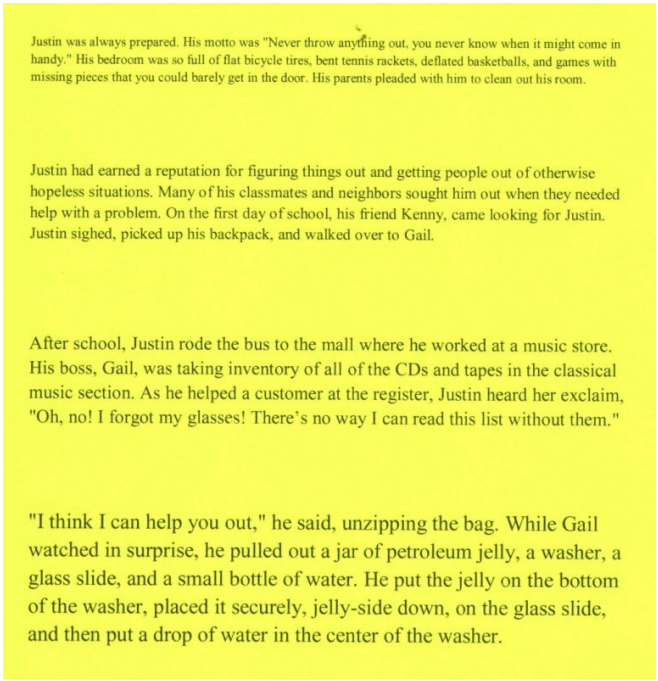

Fig. A-4. Sample test sheet-4: Blue text on yellow background.