Original Article

Effect of Different Illumination Sources on Reading and Visual Performance

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Abstract

Purpose: To investigate visual performance during reading under different illumination sources.

Methods: This experimental quantitative study included 40 (20 females and 20 males) emmetropic participants with no history of ocular pathology. The participants were randomly assigned to read a near visual task under four different illuminations (400-lux constant): compact fluorescent light (CFL), tungsten light (TUNG), fluorescent tube light (FLUO), and light emitting diode (LED). Subsequently, we evaluated the participants' experiences of eight symptoms of visual comfort.

Results: The mean age of the participants was 19.86 ± 1.09 (range: 18–21) years. There was no statistically significant difference between the reading rates of males and females under the different illuminations ($P = 0.99$); however, the reading rate was fastest among males under CFL, and among females under FLUO. One way analysis of variance (ANOVA) revealed a strong significant difference ($P = 0.001$) between males and females ($P = 0.002$) regarding the visual performance and illuminations.

Conclusion: This study demonstrates the influence of illumination on reading rate; there were no significant differences between males and females under different illuminations, however, males preferred CFL and females preferred FLUO for faster reading and visual comfort. Interestingly, neither preferred LED or TUNG. Although energy-efficient, visual performance under LED is poor; it is uncomfortable for prolonged reading and causes early symptoms of fatigue.

Keywords: Lighting; Readability; Reading Rate; Visual Comfort; Visual Performance

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INTRODUCTION

Different illumination sources have been suggested as the best standard for reading. However, this is still a conservational issue and there are some concerns among the general public regarding the appropriate light required for specific tasks.[1-4]

According to Indian Standard Code of Practice for Industrial lighting suggests Reading and writing should be used under 300-400 lux and National Electrical Code (NEC) 2011 Indian standards suggests required luminance for reading 300-700 lux followed by Central Building (CBRI) Research Institute standards of India suggests 200-500 lux for reading task.

Light emitting diode (LED) bulbs are claimed to produce the same light as other bulbs, whilst saving power and being both energy- and cost- efficient;

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there is little consideration regarding their impact on visual comfort or ocular health. Berman et al[5] provided evidence that scotopic rich fluorescent source illumination reduces pupil size and improves visual acuity; however, the effect was only measurable with low-contrast briefly-presented stimuli. Moreover, the chromaticity of light seems to influence visual stimuli; Yamagishi et al[6] compared two groups (young and elderly subjects), and found that visual performance, mood, and subjects' perception of comfortable reading and visual task performance improved under artificial LED lighting. However, Nagy et al[7] showed that differences in the spectral distribution of the ambient illumination also affect visual tasks like color and when the stimulants changed and presented on the monitor screen, they adapted to the ambient illumination. Color chromaticity also changes with LED illumination. Mott et al[8] conducted a quasi-experiment, showing that, compared to natural lighting conditions, increasing the quality of artificial light positively affected students' oral reading performance in classrooms. Lin in et al[9] studied the effect of illumination and chromatic contrast on reading performance; they found that white light was associated with better reading performance than yellow light and, thus, that light intensity, rather than color, significantly affected reading. Similarly, using various colors of LED lamps, Eo et al[10] explored the effect of classroom lighting upon student psychology; the mood of music and art rooms were altered by different colors, and this illumination variance improved students' creativity (LED lamps created a more positive feeling than fluorescent lamps). Shieh and Lin[11] showed the effect of ambient illumination and color on visual performance, using visual display terminal (VDT) screens; color performance and visual fatigue were less than illumination and color combined, and working on liquid crystal display (LCD) screens was less comfortable because of the slow accommodative velocity of users indirectly affecting visual comfort. Bowers et al[12] explained how illumination influences reading performance in macular degeneration patients; the majority of patients required a task illumination of at least 2,000 lux to increase and achieve good reading performance. However, they concluded that an ideal illumination should be determined individually for each patient using both objective (such as reading acuity) and subjective assessments to achieve better visual comfort.

Carver and Leibert[13] suggested that measuring reading rate in standard words per minute compensates for changes in difficulty level across reading materials, depending on the nature of the reading task level and purpose, and that verbal reading rate is 50% slower than silent reading. However, further studies improved that verbal reading and silent speech is mostly used to aid memory during reading, and it is not active during skim-and-scan reading type of comprehension. Simonson and Brozek[14] demonstrated the effect of illumination and visual fatigue; altering the illumination, above the optimal level, resulted in a decline in performance and an increase in fatigue. Owens et al[15] reported that convergence was a more important distance cue than accommodation in low lighting conditions; convergence was more affected than accommodation. D'Zmura[16] studied surface color changes in response to illumination, and found that the spectral properties of a trichromatic visual system recover three constant color reflectance descriptors per surface, if the color of the surface illuminant is changed. This variation in illumination creates color constancy. Legge and Bigelow [17] examined reading print size, and provided evidence that print size is critical for clear reading. Succar et al[18] showed that, among low vision patients, altering the illumination levels of visual tasks significantly affected their reading performance.

The present study aims to investigate individual reading and visual performance under different lighting sources used in daily life.

METHODS

Participants

This study was conducted in accordance with the Declaration of Helsinki, and approval by our Institutional Ethics Committee, School of Medical Sciences, at the University of Hyderabad, India. Forty participants, 20 males and 20 females, aged 18–21 years, were included. All participants were from the university student community, and were selected by quantitative random sampling. No monetary reward was provided for participation, written and verbal consent were obtained from all participants. The participant inclusion criteria were as follows: 1) emmetropia; 2) visual acuity of 6/6 in meters for distance and N_6 for near with a standard error (SE) of ≤±0.50 D;[19] 3) good general health. In addition, participants who did not have the mentioned inclusion criteria and who had a history of ocular pathology and high refractive errors and illiterate subjects were excluded from our study.

Experimental Apparatus and Setting

The current study was divided into two phases: the preliminary examination and experimental phases can be seen in Figure 1. A digital photometer (model-HS1010, Taiwan Tai Shi TES Company, China) was used for measuring light intensity. The following four illumination sources were chosen: 1) compact fluorescent light (CFL), 12 watt, 3400-Kelvin color temperature; 2) fluorescent tube light (FLUO), 20 watt, 3000-Kelvin color temperature; 3) tungsten light (TUNG), 100 watt, 3000-Kelvin temperature; 4) LED, 8 watt, 3100-Kelvin color temperature. TUNG is a warm orange color; the other three illuminations are warm white colors. An intensity 400 lux was kept constant across all four lighting sources, and monitored with digital photometer; this constant intensity was chosen based on various photometric standards provided by lighting institutes.[1-5] An average of all the standards for a near visual reading task was taken. The luminous efficiency of the illumination sources was measured for the effectiveness of luminance, and the warm light composition (400-lux intensity) for specific reading tasks. Standards were followed, according to the International Lighting Commission Code of Industrial Engineering (CIE),[20] to provide a psychophysical analog of radiance, known as luminance. A stopwatch (KadioModel KD-2004, La Kadio Company Ltd., China) was used to record reading times, and a reading pad (5 × 5 feet) was adjusted to hold the reading material. Ishihara color vision plates (38th edition, Kanehara trading Inc., Tokyo, Japan) were used to assess color vision, and a Baily Lovie 10% Contrast Sensitivity Chart was used to measure contrast. Participants were well seated in a silent and ambient illuminated room. A reading task was placed 40 cm from the participants' eyes, under overhead illumination arranged 1 m from the reading material [Figures 2 and 3].

Visual Stimuli

Reading passages of equal readability scores were generated, according to a standardized psycholinguistic text readability consensus calculator software tool.[21] The passages used for the near visual task were checked for validity and reliability using the software. The visual stimuli/passages were presented to the participants in 14 lines of Times Roman Numeral, 12-point, bold, black font, printed on a white non-glossy chart. The passages, of equal readability scores but different content, were randomly presented to participants to read under the four different illuminations. The passages were not repeated; each participant received different passages of equal readability scores. Passages were read aloud by the participants in the closed room, and checked by the experimenter for accuracy.

Experimental Procedure

The experimental procedures were performed in all four illumination-conditions (CFL, FLUO, TUNG, and LED). Passages were presented for reading under the four illuminations, after which contrast acuity was measured and the participant underwent color vision testing with the 17 Ishihara pseudo-isochromatic plates. A time gap of fifteen minutes was provided under each light source for adaptation purposes. This same procedure was repeated under all four illuminations to know the subjective response of participants. A closed-ended questionnaire feedback form relating to visual performance and symptoms [Table 1], with

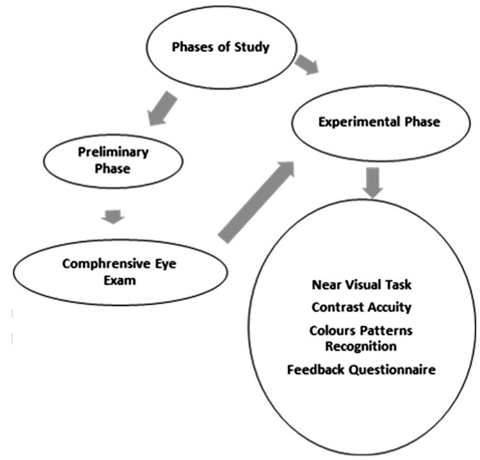

Figure 1. Flowchart of experimental protocol.

Figure 2. Participants' seating arrangements.

Figure 3. Experimental lab setup.

yes and no options, was given to participants to assess their satisfaction levels and visual comfort under the four illumination sources. The questionnaire consists of nine validated questions of good reliability, assessed by the Cronbach's alpha test (α = 0.824), and an average contingency percentage (ACP) of 90%. All illumination source sequences were changed randomly, but the tests were undertaken systematically.

Data Preparation and Statistical Analysis

All the experimental data was stored using Microsoft Excel (version 2010, Microsoft Corporation limited, Washington, USA) software. GraphPad Prism (version 7, GraphPad Software, Inc., California) statistical software was used for the statistical analyses of normal distributions using Shapiro-Wilk's tests. One-way analyses of variance (ANOVA) were used to explore the differences between all four illumination sources. Reliability and validity of the questionnaire data was assessed using Cronbach's alpha tests and ACPs calculated using SPSS (version 19, IBM Corporation, New York, USA) statistical software.

Table 1. Questionnaire form used to assess the satisfactory level of different illuminations among participants

No.	Questionnaire Variables	Yes	No
1	Did you feel excessive tearing or a desire to rub your eyes?		
2	Did you experience glare?		
3	Did you experience a burning sensation?		
4	Did you see double?		
5	Did you feel aching in your eyes?		
6	Did you experience color confusion or difficultly discriminating between colors?		
7	Did you get a headache?		
8	Did you feel grittiness?		
9	Did your eyes feel tired?		

RESULTS

This study included 40 participants (50% male, 50% female). The relationship between reading rate and illumination was not statistically significant ($P = 0.99$) in either male or female participants. Reading rate was fastest in males under CFL, and in females under FLUO. There was no statistically significant difference between illumination and contrast acuity ($P > 0.47$) or color vision ($P < 0.99$) in either male and female participants [Tables 2 and 3]. However, one-way ANOVA with Friedman's test revealed a significant association between visual performance and illumination in both males ($P = 0.001$) and females ($P = 0.002$) [Table 4]. All participants were asked to suggest satisfactory illuminations based on their experience of visual comfort and reading; most male participants suggested CFL (85%) and most female participants suggested FLUO (65%) [Figures 4-7].

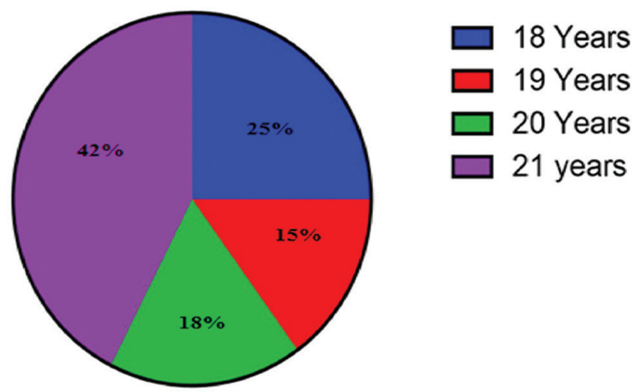

Figure 4. Pie chart showing age distribution of male and female participants ($n = 40$).

Table 2. Results of variables under different types of illumination among male participants (*n*=20) using one way analyses of variance

Independent Variables	CFL	LED	FLUO	TUNG	One way ANOVA		
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	DF	*r*	*P*
Reading Rate (CWPM)	138.2±7.5	121.05±10.9	127.08±8.53	105±8.88	0.042	0.031	0.99
Contrast Sensitivity (log units)	1±0.0	1±0.0	1±0.0	1±0.0	1.0	0.0	>0.47
Color Vision (plates recognized)	16.75±0.0	15.6±0.48	16±0.0	15.2±0.4	0.025	0.018	<0.99

CFL, compact fluorescence light; LED, light emitting diode light; FLOU, fluorescence light; TUNG, tungsten light; ANOVA, analysis of variance; CWPM, correct words per minute; *P*<0.05 is considered statistically significant

Table 3. Results of variables under different types of illumination among female participants (*n*=20) using one way analyses of variance

Independent Variables	CFL	LED	FLUO	TUNG	One way ANOVA		
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	DF	*r*	*P*
Reading Rate (CWPM)	128±11.11	126±9.57	135.75±11.08	106±15.07	0.014	0.081	0.99
Contrast Sensitivity (log units)	1±0.0	1±0.0	1±0.0	1±0.0	1.0	0.0	>0.47
Color Vision (plates recognized)	16.55±0.49	15.25±0.43	16.35±0.47	15±0.41	0.026	0.019	<0.99

CFL, compact fluorescence light; LED, light emitting diode light; FLOU, fluorescence light; TUNG, tungsten light; ANOVA, analysis of variance; CWPM, correct words per minutep; *P*<0.05 is considered statistically significant

Table 4. Friedman test showing the relationship between visual performances under different illuminations evaluated using one way analyses of variance

n=40	Gender	CFL Mean±SD	LED Mean±SD	FLUO Mean±SD	TUNG Mean±SD	*P*
Visual Performance	Male	2.44±2.12	6.88±2.71	3.5±2.69	13.66±3.1	*P*=0.001
Visual Performance	Female	2.66±1.58	8.77±3.38	2.4±1.66	13.0±3.6	*P*=0.002

CFL, compact fluorescence light; LED, light emitting diode light; FLOU, fluorescence light; TUNG, tungsten light; *P*<0.05 is considered statistically significant

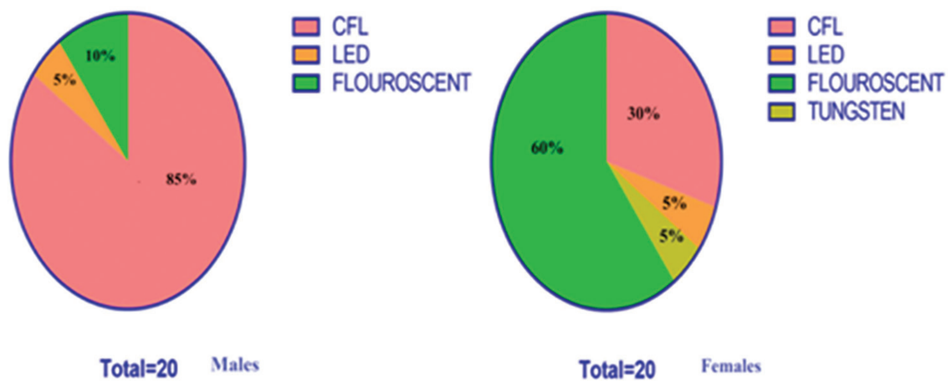

Figure 5. Pie chart showing the satisfactory levels of various illuminations.

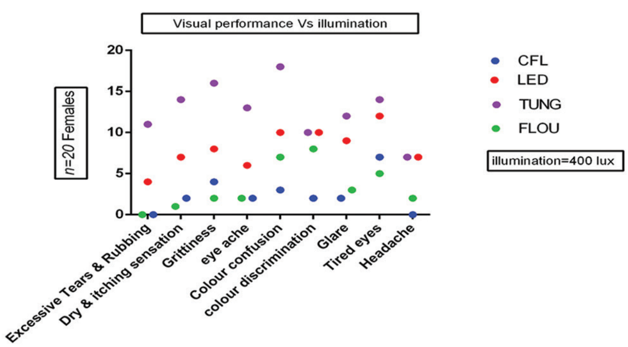

Figure 6. Scatterplot showing the visual symptoms of male participants (n = 20) under different illuminations.

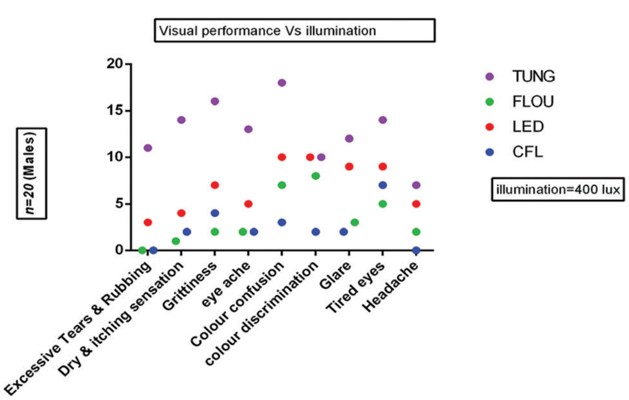

Figure 7. Scatterplot showing the visual symptoms of female participants (n = 20) under different illuminations.

DISCUSSION

This study sought to explore visual performance while reading under different illuminations, and their effect on visual comfort. No statistically significant associations between reading rate and illumination were found. However, reading rates were faster under the following illuminations:

Males: CFL > FLUO > LED > TUNG

Females: FLUO > CFL > LED > TUNG

We could not find any studies to either support or contradict our findings. However, interestingly, in our study, participants who read under LED illuminations experienced poor visual performance. This supports the study of Yamagishi et al[6] in which visual performance, mood, and psychological perception of pleasant reading and performance of visual tasks improved under artificial LED lighting. However, in our experiment, LED lighting was associated with reduced reading performance and visual discomfort, after TUNG illumination. However, at the end stage of the experiment, male participants (85%) were satisfied with CFL (it was their first choice lighting source) and female participants (65%) were satisfied with FLUO; this finding is supported by Eo et al[10] who showed that students' mood changed as a result of music and art rooms altered by fluorescent lamps, improving students' creativity and visual performance compared to colored LED lighting.

We found that reading under white fluorescent illumination resulted in better reading performance and visual comfort, consistent with Mott et al[8] who found that, compared with natural lighting, increasing the quality of artificial light positively affected students' verbal reading performance. We also found that visual comfort and performance was good under both CFL and FLUO, similar to Simonson and Brozek[14] who found that maintaining optimum illumination for visual tasks improved visual performance and reduced ocular fatigue.

Nevertheless, there were few limitations to our study that need to be addressed in future work. It is unclear how the spectral distribution of artificial lighting influences the visual system and visual performance. Future studies should be conducted on different age groups and larger sample sizes. Moreover, changing standard color vision tasks may improve our understanding of the impact of lighting on visual tasks.

In conclusion, we found a weak association between illumination type and reading rate. However, our findings suggest that most males (85%) prefer CFL and most females (65%) prefer FLUO, as opposed to LED and TUNG illuminations. Thus, whilst LED lighting is energy- and cost- efficient, visual performance under LED is poor and it is not suitable for prolonged visual tasks like reading and writing as it may also cause early ocular fatigue. Visual discomfort was highest under both TUNG and LED illuminations.

Clinically, these findings suggest an association between illumination type and visual performance, and that improper illumination and intensity may cause early eye-fatigue problems. The current study may also raise patient awareness as to the importance of illumination, and support maintenance of a steady relationship with optometrists and eye care specialists. It is fundamental to educate patients as to the importance of visual task standards and illumination in reading, given their role in day-to-day life.

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Conflicts of Interest

There are no conflicts of interest.

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