Influence of spectral distribution on accommodation—vergence and reading performance

Shiva Ram Male[1,2], Rishi Bhardwaj[1], Chiranjib Majumder[2]

[1]School of Medical Sciences, University of Hyderabad, Telangana, India; [2]R J N School of Optometry, Gwalior, Madhya Pradesh, India

Contributions: (I) Conception and design: R Bhardwaj, SR Male; (II) Administrative support: R Bhardwaj; (III) Provision of study materials or patients: R Bhardwaj, SR Male; (IV) Collection and assembly of data: SR Male, R Bhardwaj; (V) Data analysis and interpretation: SR Male, C Majumder; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Shiva Ram Male, M.sc (Optometry and Vision sciences). Dr. Rishi Bhardwaj Visual psychophysics Laboratory, School of Medical sciences, University of Hyderabad-46, Telangana, India. Email: shivaramopto@uohyd.ac.in.

Background: To assess the influence of different spectral energy distribution on accommodation, vergence and reading performance.

Methods: A Randomized experimental study was conducted after getting the approval of the Ethical Committee of University of Hyderabad. Forty participants with an age group of 18–21 years was integrated, out of which 50% was male and 50% was female. Subjects with emmetropia and no history of ocular pathology were included in the study. Near point of accommodation (NPA) & near point of convergence (NPC) was measured with the help of royal air force (RAF) ruler followed by near visual task of a readability passage.

Results: A statistically significant result was obtained when reading rate, reading speed and NPC was compared among different spectral distribution of light (P<0.001) except NPA (P=0.43). Post hoc analysis showed a significant difference (P<0.001) when tungsten was compared with fluorescent light (FLOU), compact fluorescent light (CFL), and light emitting diode (LED) for reading rate, reading speed and NPC. But there is no noteworthy difference exist when fluorescent was compared with CFL for reading rate (P=0.530) & reading speed (P=0.595). Similarly, LED also showed no considerable difference when compared with CFL (P=0.682) and fluorescent (P=0.490) for NPC. When NPA was assessed within the group LED showed insignificant difference with CFL (P=0.205) and fluorescent (P=0.275) similar like fluorescent and tungsten (P=0.482).

Conclusions: This study concluded that reading performance (reading rate and reading speed) and NPC has a significance change if we use inappropriate lighting during visual tasks. It will cause visual fatigue and strain after sustained near work. In addition, tungsten spectral energy influences the convergence which can also show an impact on reading and near visual tasks because of its brightness and miosis. Prolonged reading and working under this lighting can cause convergence disorders and visual fatigue.

Keywords: Accommodation; convergence; reading rate; reading speed; readability; spectral distribution; correct word per minute (CWPM)

Introduction

The process of which the crystalline lens varies its focal length in response to changes in the vergence of incident light is the definition of accommodation (1). Accommodation is also associated with pupil constriction (miosis) and convergence during near fixation which are termed as the near vision complex or near triad (2). In 1855, Herman von Helmholtz described the changes taking place in accommodation as constriction of pupil, moving forward of pupillary margin of the iris and the anterior surface of the lens. The anterior surface of lens becomes more convex

while the posterior surface becomes slightly more convex (1). Most of the studies proved the influence of accommodation on electronic devices and addressed one of the rationales for visual fatigue during reading. Hue *et al.* reported that reading soft copy material from electronic devices cause change in accommodation compare to hardcopy printed material (3). In addition viewing angle and gaze from screen also influences the accommodation (4). Simonson *et al.* in his study stated that visual performance is reduced due to accommodation fatigue which was influenced by the variety of room illumination (5). However, Hennessy *et al.* proves that during accommodation pupil size is reduced, the amplitude of accommodation is diminished and approaching a fixed intermediate resting focus corresponding to approximate distance of the visual task (6). Miller *et al.* postulated that a 3-hour exposure to visual task did not produce any significant changes in dark focus eventhough it is a demanding visual task. He also quoted that accommodation remains same at dark focus. So, the fatigue can be observed when accommodative effort is required (7). Individual differences such as age, race, gender and refractive error might influence accommodation parameters (8). However, Yavas *et al.* Showed that gender has insignificant influence on amplitude of accommodation (9). Reading performance is one of the important issue that need to be addressed while discussing about reading at near. Carver *et al.* suggested that measuring reading rate in standard words per minute is due to compensate for changes in difficulty level across reading material, nature of reading task level and purpose of reading (10). Huey *et al.* study explains oral reading rate is 50% slower than silent reading (11). Later on Carver *et al.* proved that silent speech is mostly used to aid memory during reading hence it is not active during skim and scan of reading (10). Owens DA *et al.* studied convergence in relation to the low illumination and explained that convergence is most important distance cue than accommodation in low lighting conditions. So, convergence is more affected than accommodation (12). Current paper tried to conduct an experiment on different spectral distribution of light, to show their influence on reading rate, reading speed, accommodation and convergence.

Methods

Participants

This study includes forty subjects irrespective of their

gender and race. The subjects were within an age group of 18–21 years pursuing their bachelor degree. A written informed consent was obtained from all the participants and an approval (UH/IEC/2015/134) to conduct the study was obtained from the Ethical Committee of the School of Medical Sciences, University of Hyderabad, India. Participants are the student of University of Hyderabad and a randomized sampling was used with equal opportunity and equity. No monetary reward was offered to the participants in this experiment. Subjects with emmetropia (visual acuity 6/6, 20/20) and devoid of any ocular pathology were included in this study.

Materials & experimental setup

This experimental quantitative study design was divided into two phases: preliminary examination and experimental phase. Preliminary examination includes comprehensive eye examination and experimental phase includes calculating intensity of light [compact fluorescent light (CFL) 12 watt, fluorescent light 20 watt, tungsten 100 watt, light emitting diode (LED) 8 watt] with the help of digital photometer model-(HS1010). Near point of accommodation (NPA) and near point of convergence (NPC) were measured with the help of royal air force (RAF) ruler (Zeiss clement Clarke model). To assess the reading speed and reading rate, readability score was checked. Equal readability score passages were created with the help of "Free Readability Text Consensus Tool" (13) and then from the readability score the reading speed and reading rate was calculated [reading speed = (total no. of words/time taken to complete the passage) × time in seconds; reading rate = CWPM – errors read). Text passages with equal readability score was printed on a nonglossy white paper with hundred percent contrast can see in *Figure 1*. Reading time was measured with the help of stop watch (Kadio model KD-2004). Reading pad of 5×5 feet was used to hold reading material at 40 cm from the subject along with an overhead illumination placed at a distance of 1 meter.

Experimental procedure

All participants were instructed about their job throughout the experiment, prior to the experiment. All tests were carried out under four lighting conditions (LED, CFL, fluorescent and tungsten) within an interval of 15 minutes. An interval of 15 minutes was allotted to overcome the light adaptation effect. Before starting the experiment, a randomized sequence was generated with the help of

Germination is the growth of a plant contained within a seed; it results in the formation of the seedling. It is also the process of Reactivation of metabolic machinery of the seed resulting into the emergence of radicle and plumule. The seed of a vascular is a small package produced in a fruit or cone after the union of male and female reproductive cells. All fully developed seeds an embryo and, in most plant species some store of food reserves, wrapped in a seed coat. Some plants produce varying seeds that lack embryos; these are called empty seeds and never germinate. Dormant seeds are ripe seeds that do not germinate Because they are subject to external environmental conditions that prevent the initiation of metabolic processes and cell proper conditions, the seed begins to germinate and the embryonic tissues resume growth, developing towards a seedling. Seed germination depends on both internal and external conditions. The most important external factors include right temperature, water, oxygen or air and sometimes light or darkness. Various plants require different variables for germination. Often this depends on the individual seed variety and is closely linked to the ecological conditions of a plant's natural habitat For some seeds, their future germination response is affected by environmental conditions during seed water is required for germination. Mature and roller coaster seeds are often extremely dry and need to take in significant amounts of water, relative to the dry weight of the seed, before cellular metabolism and growth can resume. Most seeds need enough water to moisten the seeds but not enough to soak them. The uptake of water by seeds is called imbibitions, which leads to the growth from seed.

Readability Consensus
Grade Level: 12 to 13th class
Reader's Age: 18-19 yrs. old (college level entry).

Figure 1 Readability passage used for near visual task.

Table 1 Friedman Test showing the relation between illumination and reading rate

Variable	Mean ± SD				P value
	CFL	TUNG	FLOU	LED	
Reading rate	133.52±12.15	105.87±12.43	128.83±23.21	123.75±10.74	<0.001

P<0.05 is considered significant. CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

Table 2 Friedman Test showing the relation between Illumination and Reading speed

Variable	Mean ± SD				P value
	CFL	TUNG	FLOU	LED	
Reading speed (CWPM)	137.07±11.92	112.50±12.31	135.45±10.98	128.55±10.47	<0.001

CWPM, correct word per minute; CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

computer software and each individual has to follow that sequence for measuring reading rate, reading speed, NPC and NPA. Throughout the experiment a constant intensity of light (400 lux) was maintained for all four illuminations with the help of digital photometer.

Data preparation and analysis

All data was entered in Microsoft Excel version 2010 and statistical analysis was carried out with the help of IBM-SPSS 21.0 software. G-power software was used to calculate the sample size with a medium effect size. Normality of the data was assessed by Shapiro-Wilk test. Based on the normality data, Friedman test was chosen to compare the reading rate, reading speed, NPA and NPC with four different spectral distribution of light. Post hoc analysis was done within the groups by using Wilcoxon signed rank test. A P value of <0.05 was considered significant.

Results

This study includes 40 participants with an age group of 18–21 years, out of which 50% male and 50% female. A statically significant result was obtained when Reading rate, Reading speed NPC, NPA was compared among different spectral distribution of light (P<0.001) as shown in *Tables 1-4* respectively. Post hoc analysis showed a significant difference (P<0.001) when tungsten was compared with fluorescent light (FLOU), CFL, and LED for reading rate reading speed and NPC. But there is no significant difference exist when fluorescent was compared with CFL for reading rate (P=0.530), reading speed (P=0.595) as shown in *Tables 5 and 6*

Table 3 Friedman Test showing the relation between illumination and NPC (n=40)

Variable	Mean ± SD				P value
	CFL	TUNG	FLOU	LED	
NPC (cm)	7.10±0.11	6.85±0.11	7.15±0.16	7.13±0.14	<0.001

NPC, near point of convergence; CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

Table 4 Friedman Test showing the relation between illumination and NPA

Variable	Mean ± SD				P value
	CFL	TUNG	FLOU	LED	
NPA (cm)	13.11±1.10	13.54±0.34	13.51±0.31	13.36±0.37	0.43

NPA, near point of accommodation; CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

Table 5 Comparision within the groups was done by Wilcoxon signed ranks test for reading rate and illumination

Types of illumination		Z value	P value
CFL	TUNG	−5.163	<0.001
	FLOU	−0.629	0.530
	LED	−3.153	0.002
FLOU	TUNG	−4.639	<0.001
	LED	−3.316	0.004
	CFL	−0.629	0.530
LED	CFL	−3.153	0.002
	FLOU	−3.316	0.004
	TUNG	−4.900	<0.001
TUNG	FLOU	−4.639	<0.001
	CFL	−5.163	<0.001
	LED	−4.900	<0.001

P<0.05 is considered significant. CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

Table 6 Comparision between the groups was done by Wilcoxon signed ranks test for reading speed and illumination

Types of illumination		Z value	P value
CFL	TUNG	−5.053	<0.001
	FLOU	−0.531	0.595
	LED	−2.938	0.003
FLOU	TUNG	−5.075	<0.001
	LED	−3.383	0.001
	CFL	−0.531	0.595
LED	CFL	−2.938	0.595
	FLOU	−3.383	0.001
	TUNG	−4.807	<0.001
TUNG	FLOU	−5.075	<0.001
	CFL	−5.053	<0.001
	LED	−4.807	<0.001

P<0.05 is considered significant. CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

respectively. Similarly, LED showed no significant difference when compared with CFL (P=0.682) and fluorescent (P=0.490) for NPC as shown in *Table 7*. When NPA was assessed within the group LED showed no significant difference with CFL (P=0.205) and fluorescent (P=0.275) similar like fluorescent and tungsten (P=0.482) as shown in *Table 8*.

Discussion

Though considerable amount of research is going on

around the world on spectral distribution and eye, we still need to have a good understanding about its influence on our visual system. Our study not only aimed to assess the influence of different spectral energy distribution of lighting on accommodation and vergence but also the reading performance (reading rate, reading speed). This study showed a significant effect (P<0.001) of spectral distribution of light on reading performance which is supported by Lin *et al*. In 2014, Lin *et al*. concluded that light intensity (P=0.002) and background color (P=0.003)

Table 7 Comparision between the groups was done by Wilcoxon signed ranks test for NPC and illumination

Types of illumination		Z value	P value
CFL	TUNG	−5.464	<0.001
	FLOU	−5.512	<0.001
	LED	−0.410	0.682
FLOU	TUNG	−5.333	<0.001
	LED	−0.690	0.490
	CFL	−5.512	<0.001
LED	CFL	−0.410	0.682
	FLOU	−0.690	−0.490
	TUNG	−5.158	<0.001
TUNG	FLOU	−5.333	<0.001
	CFL	−5.464	<0.001
	LED	−5.15	<0.001

NPC, near point of convergence; CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

Table 8 Comparision between the groups was done by Wilcoxon signed ranks test for NPA and illumination

Types of illumination		Z value	P value
CFL	TUNG	−3.086	0.002
	FLOU	−2.189	0.029
	LED	−1.268	0.205
FLOU	TUNG	−7.03	0.482
	LED	−1.091	0.275
	CFL	−2.189	0.029
LED	CFL	−1.268	0.205
	FLOU	−1.091	0.275
	TUNG	−2.274	0.023
TUNG	FLOU	−7.03	0.482
	CFL	−3.086	0.002
	LED	−2.274	0.023

NPA, near point of accommodation; CFL, compact fluorescent light; FLOU, fluorescent light; LED, light emitting diode; TUNG, tungsten light.

having significant influence on reading performance (14). Although both the studies supporting each other but still there are few discrepancies exists in terms of methodology. This study not only kept intensity and background color fixed but also checked readability score of each passage which was not measured in Lin *et al.* study. Apart from that Succar TA *et al.* also emphasized extra lighting during near task for low vision patients than normal lighting which will be more beneficial for their reading performance (15). In another study by Simonson *et al.*, reported that changes in optimum level of illumination causes visual fatigue and deterioration of performance (16). Current study also showed that reading rate and reading speed was affected more in tungsten followed by LED. This effect leads to visual fatigue due to the focusing changes with different spectral distribution of light.

This study showed that NPC (P<0.001) is significantly changing with different spectral distribution of light. Although it was observed that NPC with tungsten light is better than fluorescent, CFL and LED, but subjects experience more comfort with fluorescent, CFL and LED while doing near task. This study result is supported by Owens DA *et al.* where he has mentioned convergence is the most important distance cue than accommodation in low lighting conditions and chances of affecting convergence is more than accommodation (12).

Moreover this study also proved, NPA (P=0.43) has no significant effect on different spectral distribution of light. But post hoc analysis showed a significant difference between tungsten—CFL (P=0.002) and tungsten—LED (P=0.023). Aggarwala *et al.* in his study concluded that accommodation increases and lag decreases when a stimulus of spectral bandwidth is varied which contradict current study findings. The discrepancy between the two studies is because methodology difference (17).

Conclusions

This study concluded that reading performance (reading rate and reading speed) and near point of convergence significantly changes with different spectral distribution of light. However, accommodation has not much significant effect when changing the spectral distribution of light. Tungsten spectral energy influencing the convergence which can also shows an impact on reading and near visual tasks.

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Footnote

References

1. Grosvenor T. Primary care optometry. 5th edition. London, UK: Elsevier Health Sciences, 2007.
2. Von Noorden GK. Binocular vision and ocular motility: Theory and Management of Strabismus. Ann Arbor, Michigan: Mosby, 2002.
3. Hue JE, Rosenfield M, Saá G. Reading from electronic devices versus hardcopy text. Work 2014;47:303-7.
4. Kundart J, Tai YC, Hayes JR, et al. Real-Time Objective Measurement of Accommodation While Reading. Available online: https://www.oepf.org/sites/default/files/22-5-KUNDART_0.pdf
5. Simonson E, Brozek J. Effects of illumination level on visual performance and fatigue. J Opt Soc Am 1948;38:384-97.
6. Hennessy RT, Iida T, Shina K, et al. The effect of pupil size on accommodation. Vision Res 1976;16:587-9.
7. Miller RJ, Pigion RG, Wesner MF, et al. Accommodation fatigue and dark focus: the effects of accommodation-free visual work as assessed by two psychophysical methods. Percept Psychophys 1983;34:532-40.
8. Kragha IK. Accommodative vergence and related findings for a Nigerian population. Ophthalmic Physiol Opt 1985;5:435-9.
9. Yavas GF, Oztürk F, Küsbeci T, et al. Evaluation of the change in accommodation amplitude in subjects with pseudoexfoliation. Eye (Lond) 2009;23:822-6.
10. Carver RP, Leibert RE. The effect of reading library books at different levels of difficulty upon gain in reading ability. Reading Research Quarterly 1995;1:26-48.
11. Huey EB. The psychology and pedagogy of reading. London, UK: The Macmillan Company, 1908.
12. Owens DA. The Resting State of the Eyes: Our ability to see under adverse conditions depends on the involuntary focus and convergence of our eyes at rest. American Scientist 1984;1;72:378-87.
13. Free Text Readability Consensus Calculator. Available online: http://www.readabilityformulas.com/free-readability-formula-tests.php
14. Lin CC, Huang K. Effects of Lighting Color, Illumination Intensity, and Text Color on Visual Performance. International Journal of Applied Science and Engineering 2014;12:193-202.
15. Succar TA, Walker L, Kendrick K, et al. Functional impact of task lighting on reading with low vision. Investigative Ophthalmology & Visual Science 2015;56:2217.
16. Simonson E, Brozek J. The effect of spectral quality of light on visual performance and fatigue. J Opt Soc Am 1948;38:830-40.
17. Aggarwala KR, Kruger ES, Mathews S, et al. Spectral bandwidth and ocular accommodation. J Opt Soc Am A Opt Image Sci Vis 1995;12:450-5.