

NO CHANGES IN THE ACCOMMODATIVE STIMULUS-RESPONSE CURVE BUT VARIED LAG OF ACCOMMODATION AFTER A 30-MIN ELECTRONIC NEAR TASK UNDER FOUR DIFFERENT LIGHTING CONDITIONS AMONG MYOPIC YOUNG ADULTS

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Abstract: The prevalence of myopia is increasing worldwide, mainly in Asian countries. Light-emitting diodes (LED) and low light levels used for homework after school was thought to contribute to myopia development. This study explored how near work and lighting affect the accommodation response. Thirty myopic young Malay adults (18-23 years old) were recruited. The ASRC was measured after performing a 30-min near the electronic task at 20cm using a binocular open-field autorefractor (Grand Seiko, Shin-Nippon) at 6.0 m, 1.0 m, 0.5 m, 0.33 m, 0.25 m, and 0.20 m under four different lighting conditions (Fluorescent 6500K, Fluorescent 3000K, LED 6500K, LED 3000K). A significant flattening in the ASRC gradient was noted when comparing pre and post-measures following the near-vision task for all lighting conditions ($p < 0.01$). ASRC gradient differences were not affected by lighting conditions (One-way repeated measure ANOVA $F_{(3,87)} = 0.84$, $p > 0.05$). ASRC gradient was affected only after 30 minutes of near work $F_{(3,87)} = 0.049$, $p < 0.05$). The increment in the accommodative inaccuracy was apparent following prolonged close work. Types of light were not imperative. This information on short-term exposure can be useful for interior light choice of buildings. The effect of long-term exposure requires further investigation.

Keywords: Accommodative stimulus-response curve, near task, lighting, myopes.

Introduction

The prevalence of myopia is increasing worldwide but most rapidly in East and South Asia (Hashemi *et al.*, 2018). Genetics alone cannot account for this, which led to a resurgence of research related to the multifaceted environmental factors associated with myopia, including defocus and lighting quality (Cai *et al.*, 2019; Haarman *et al.*, 2020). Myopia is associated with less time spent outdoors and prolonged periods of near-intensive work (Zhang & Deng, 2019). The mechanism by which greater time spent outdoors is protective against myopia development is unclear. Still, it may be due to the tendency to do more distance work outdoors, the spectral composition of natural daylight, or the intensity of outdoor light (Lingham *et al.*, 2019). Natural daylight and artificial light are different in the spectrum. The full light spectrum only exists in natural daylight. Outdoor natural

daylight comprises visible, ultraviolet, and infrared radiation (Thorne *et al.*, 2009). Outdoor natural daylight has a greater composition of shorter wavelengths than indoor artificial lighting (Thorne *et al.*, 2009; Strickland *et al.*, 2020). The effect of light spectral distribution on human refractive error is unknown.

In animal research, smaller amounts of form-deprivation myopia have been produced in chicks using diffusers exposed to short blue wavelengths and ultraviolet lighting than red or white lights (Wang *et al.*, 2018). Conversely, infant monkeys reared under red filters absorbing shorter wavelengths have produced a more hyperopic refractive error (Smith *et al.*, 2015). Choroidal thickness thinned after broadband light, red light and dark exposure but not after blue light exposure (Thakur *et al.*, 2021). Light of an intensity similar to the outdoors is protective against experimental myopia in animal models,

possibly through the regulation of circadian rhythm, the intrinsic body clock (Strickland *et al.*, 2020). In the chick eye, exposure to bright light during the night interrupts the normal circadian rhythm resulting in myopic growth (Nickla & Totonelly, 2016). Low light levels favour myopia development, and elevated light levels protect against it (Landis *et al.*, 2021). Violet light exposure has been suggested to be a preventive strategy against myopia progression in adults (Torii *et al.*, 2017). There were two contradictory conclusions regarding the association between the development of myopia and night-time ambient light exposure during sleep in children (Quinn *et al.*, 1999; Zadnik *et al.*, 2000). One found a strong association in their investigation on children before they reached two years of age (Quinn *et al.*, 1999), while the other could not find a link in a sample of schoolchildren (Zadnik *et al.*, 2000).

The intensity of room lighting may also play a role in myopia development. Indoor light is still much lower than the intensity of outdoor light (Pan *et al.*, 2018; Wildsoet *et al.*, 2019). A study on direct light exposure measurement on myopic and nonmyopic children using wearable light sensors suggested that the rod pathways stimulated by dim light exposure could be important to human myopia development and bright light exposure (Landis *et al.*, 2018). Optimal strategies for preventing myopia with environmental light may include dim and bright light exposure (Zhang & Zhu, 2022). Increased light exposure has been reported to reduce myopia progression in young adults (Read *et al.*, 2018). Natural light exposure early in life has been suggested to foster normal emmetropisation later in life (Wang *et al.*, 2015). The role of dim light exposure in preventing myopia has also been advocated because a broad range of light levels involving both rod and cone pathways was asserted to be essential in refractive development (Landis *et al.*, 2018). Despite the inconclusive link between myopia and night-time ambient light, long-term ocular exposure to the ambient light during daytime indoor activities might affect the visual system differently. Strong evidence between lighting

and myopia in animal studies suggested the importance of studying the effect of ambient lighting in buildings for indoor activities on the visual system. The invention and evolution of light bulbs throughout the industrial revolution changed how we used indoor space in buildings and increased the length of the work duration. Affordable artificial lighting allows us to sleep much later and engage in indoor activities inside smaller visual spaces until the wee hours.

There were various artificial lighting types, such as incandescent, fluorescent, and light-emitting diodes. The incandescent light bulbs had short lifespans besides expensive production and inefficient energy usage (MacIsaac *et al.*, 1999). The incandescent light spectrum is dynamic and continuous, where all visible colours are present. Fluorescent lights use discharge technology. It lasts longer and is more efficient than incandescent bulbs. The fluorescent light has an emission spectrum because the light source is the output of electrified gas (Ribarich, 2009). Fluorescent light only produces a limited amount of colour. A compact fluorescent light bulb was designed to be used in a residential application. Light-emitting diode technology (LED) is increasingly used due to its energy-saving properties. Exposure to LED lights has been suggested to cause irreparable harm to the human eye's retina (Behar-Cohen *et al.*, 2011). LEDs use a semiconductor to convert electricity into light, are often small in area and emit light in a specific direction, reducing the need for reflectors and diffusers that can trap light. LED produces emissions spectrums too. An LED light emits only one colour. The pure light from an LED is generally blue. The wavelength of the LED and fluorescent light produced can be selected. Therefore, fluorescent lights and LED lights vary in their spectral power distribution. Indoor lighting is commonly separated into cool and warm categories. The cool light comes from the blue part of the colour spectrum. In contrast, the warm light comes from the red part of the colour spectrum. Cool lighting suits practical applications, while warm lighting is best for living and resting areas (Lee *et al.*, 2014).

The association study between the types of home lights (incandescent, fluorescent, and LED) and the prevalence of myopia in children has implied that using LED lights for homework after school might contribute to myopia development among school-aged children (Pan *et al.*, 2018). A longer axial length is associated with a light source less similar to outdoor light in spectral distribution and intensity (Li *et al.*, 2015). The intensity of near work was also connected to myopia progression (Ip *et al.*, 2008; Rose *et al.*, 2008). Prolonged near work relates to accommodative lag (Tosha *et al.*, 2009) and visual complaints (Owens & Wolf-Kelly, 1987; Sterner *et al.*, 2006). Myopic subjects exhibit a more significant lag of accommodation than nonmyopic subjects (McBrien & Millodot, 1986; Gwiazda *et al.*, 1993; Abbott *et al.*, 1998). The accommodative stimulus-response curve (ASRC) is an indicator of the functionality of the accommodative response that varies with age, target size, measurement method, and refractive error (Yeo *et al.*, 2006). Myopes demonstrate reduced accommodative response at near and more significant accommodative errors than non-myopes (Gwiazda *et al.*, 1993; Abbott *et al.*, 1998; Millodot, 2015). Accommodative lag results in hyperopic defocus could either trigger or consequence myopic growth (Mutti *et al.*, 2006, 2017). The objective of this study was to explore further the interaction between near work and lighting conditions in affecting accommodation closely linked to myopia development under a controlled laboratory set-up. We examined the near-task effect on the accommodative stimulus-response curve (ASRC) under four different lightings among myopic subjects.

Materials and Methods

Subject

The study adhered to the Helsinki Declaration and ethical approval was granted by the institutional review board [600-IRMI (5/1/6)]. Informed consent was obtained before all measures. Thirty myopic Malay young adults (23 females, seven males) aged 18 to 23 years old (mean = 19.90 years; SD = 2.05 years)

were recruited. Inclusion criteria included best-corrected monocular visual acuity equal to or better than 6/6, less than 0.50 D of astigmatism in either eye, the difference between eyes of not more than ≥ 1.00 D, no known history of binocular disorders and no known history of ocular disease. Myopia was defined as spherical equivalent refraction (SER = sphere + $\frac{1}{2}$ cylinder) of -0.50 D or more. Participants were fitted with daily disposable contact lenses (Johnson & Johnson 1-Day Acuvue moist, Ireland). Subjective refraction was performed to obtain the best-corrected visual acuity. SER was calculated from the spectacle prescription to determine the contact lens power.

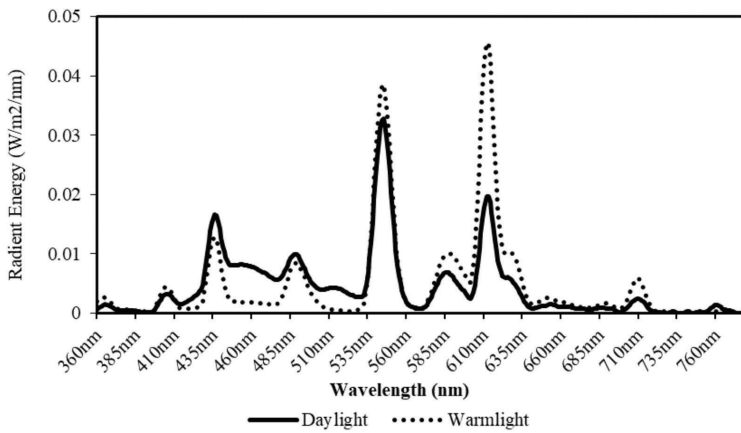
Experimental Room

The experiment was conducted in a windowless room (6 m x 4.5 m x 3 m) covered by a black coloured curtain to minimise interference by glare and external ambient light. Each ceiling-mounted lighting unit consisted of six tubular lights (total length of 1.2 m). Four types of lighting were used: Fluorescent daylight (Light 1), warm fluorescent light (Light 2), LED daylight (Light 3) and LED warm light (Light 4). The warm light was selected to denote natural lighting because it emitted a yellowish colour and looked natural. Daylight contained more blue light and looked brighter than warm light. A daylight of 6500K signified a bright blue range. The lighting information is further described in Table 1. Illumination and CCT were recorded for each light source using a lux meter (Lutron LX 101-A) and an illuminance spectrophotometer (Konica Minolta CL-500A).

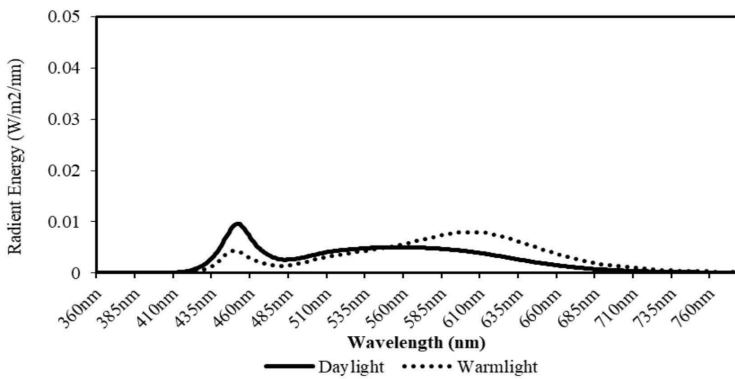
Fluorescent and LED lights were selected due to the accessibility of the product and market-driven inclinations of longer lifespans and efficient energy usage. The light of the fluorescent category (Light 1 & Light 2) contributed more from the green to red range of the visible colour spectrum. Light 3 presented a unique violet range of the visible colour spectrum for the LED category, while Light 4 showed a more balanced visible colour spectrum range. The spectral power distribution of the lighting is plotted in Figure 1.

Table 1: Information on the four types of lighting under investigation

Characteristics	Light types			
	Light 1	Light 2	Light 3	Light 4
Brand/Type	GE/F36W/T8/865/Tri-Plus	GE/F36W/T8/830/Tri-Plus	GE/LED16W/T8/865/Basic	GE/LED16W/T8/830/Basic
Light type	Fluorescent daylight	Fluorescent warm light	LED daylight	LED warm light
Illumination (lux)	306.4 lux	267.13 lux	324.4 lux	259.1 lux
Manufacturer CCT	6500 K (DL)	3000K (WL)	6500K (DL)	3000K (WL)
Measured CCT	6655 K	3054 K	6453 K	3034 K



(A) Fluorescent light



(B) LED light

Figure 1: The spectral power distribution (SPD) for Light 1, Light 2, Light 3, and 4. Figure 1 (A) shows the spectral power distribution pattern for fluorescent light; Light 1 (Fluorescent daylight) & Light 2 (Fluorescent warm light). Figure 1 (B) shows the spectral power distribution pattern for LED lights, Light 3 (LED daylight). Light 4 is (LED warm light). All spectral power distribution pattern was plotted using the same scale

Near Task Investigation

A matte rectangle working table (1.5 m x 0.46 m x 0.72 m) with a height-adjustable chair was used for near-task investigation. The table was placed in the centre of the room and was consistent for all light types. The near vision task comprised an electronic game using an iPad mini (Model, A1490, Apple, USA) at 20 cm for 30 min. A string was attached to two metal book stands to ensure the viewing distance remained constant at 20cm from the screen. The display size area was 193.3 cm² with 1536 x 2048 pixels per inch (ppi) in Light Emitting Diode LED-backlit IPS LCD.

The accommodative responses were measured using binocular open-field autorefractometry (Grand Seiko WAM-5500, Japan) before and after a 30-minute near task. The accommodative stimulus target consisted of six single high contrast 6/9 Landolt C letters with a crowding bar. The luminance of the target was measured as 80.4 cd m⁻² at 6 m and 8.3 cd m⁻² at 0.2 m. The target was presented at six distances (6 m, 1 m, 0.5 m, 0.33 m, 0.25 m and 0.20 m, equating to an accommodative demand of 0D, 1D, 2D, 3D, 4D and 5D, respectively. Ten readings were taken at each distance for the right eye only. Measurement errors due to blinking and fixation loss were excluded. Pupil size was monitored to ensure pupil size was greater than 2.3 mm to maintain a static accommodation measurement (Winn *et al.*, 1989).

The sequence of exposure to the four types of light was assigned at random for each subject. The lights were switched on at least 10 min before measurements to minimise light fluctuation. Subjects were exposed to five minutes of light adaptation to ensure photoreceptor sensitivity adjustment to surrounding lighting changes (Govardovskii *et al.*, 2000). During the 5 minutes adaptation, the subject was instructed to look at the distance target (6 meters). Fixation targets were presented to the subjects at six descending distances during pre-task accommodation measurement. Post-task accommodative responses were measured after the near-task activity for each distance, as mentioned earlier. This procedure was

repeated for four lighting conditions. Subjects were seated in a dark room between different lighting experiments to minimise the after-effect of light adaptation.

Statistical Analysis

All statistical tests were performed using SPSS software version 21 (IBM Corporation, Armonk, NY, USA) using a statistical significance level of 5% throughout ($p < 0.05$). The accommodative response was plotted against each accommodative stimulus for each lighting condition for each subject. Linear regression ($y = mx + c$) was plotted, and the ASRC gradient was calculated. A one-way repeated measures ANOVA was used to compare the difference in gradient at each of the four lighting conditions and the ASRC gradient before and after the near task for each light condition.

Results and Discussion

The pre-ASRC and post-ASRC slopes were plotted in Figure 2 to illustrate the near-task effect in all four lighting conditions. A significant flattening in the ASRC slopes was found after 30-mins near-vision tasks. The highest mean difference in slope gradient was 0.05 in Light 1 ($F_{(1,29)} = 35.52$, $p < 0.01$) and followed by Light 3 with a mean difference of 0.04 ($F_{(1,29)} = 17.57$, $p < 0.01$). Light 2 ($F_{(1,29)} = 8.59$, $p > 0.05$) and Light 4 ($F_{(1,29)} = 12.66$, $p > 0.05$) did not show a significant difference with a mean difference of 0.03. Initially, lag of accommodation as indicated by ASRC slopes before performing near task showed no significant differences under different lightings ($F_{(3,87)} = 0.277$, $p > 0.05$). However, the post-near-work ASRC slope differences revealed a significant difference between different lighting conditions ($F_{(3,87)} = 2.721$, $p < 0.05$).

As calculated by the accommodative demand and response differences, the lag of accommodation was plotted (Figure 3) and analysed between different lighting conditions. The discrepancy of the lag of accommodation was apparent after performing near tasks. Before

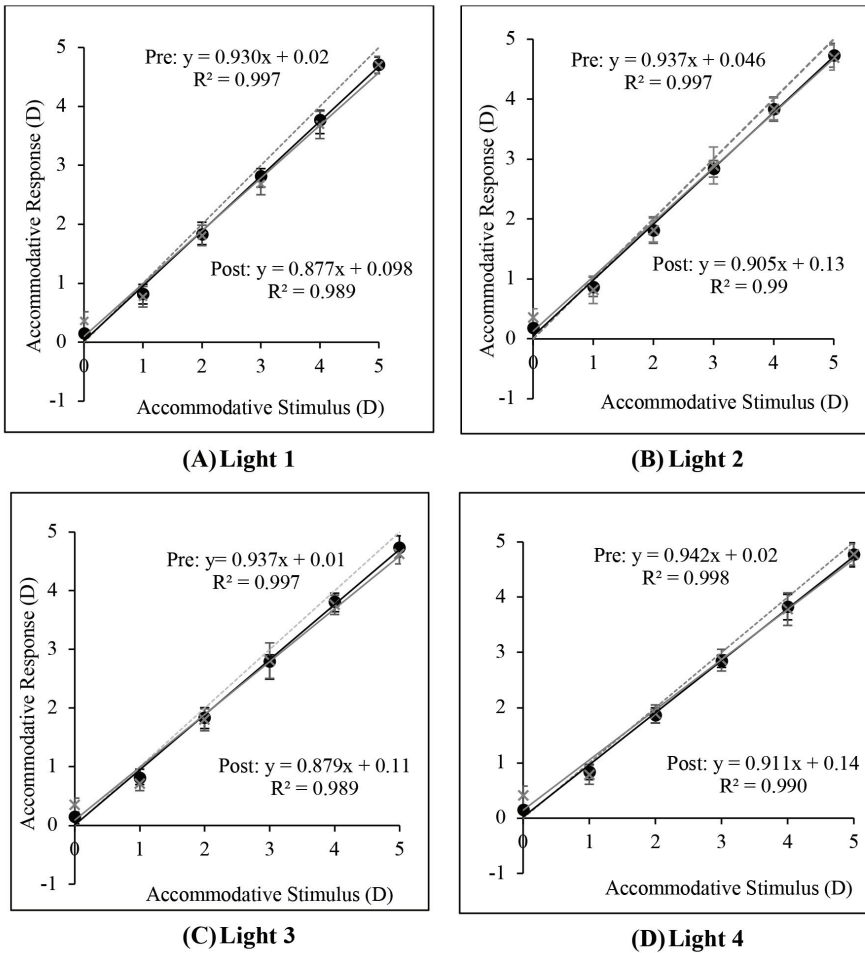


Figure 2: The Accommodation Stimulus Response Curve (ASRC) Pre and Post performing the near task under Light 1 (Fluorescent daylight), Light 2 (Fluorescent warm light), under Light 3 (LED daylight), and Light 4 (LED warm light). The circle sign indicates the Pre-ASRC slope, while the crossed symbol indicates the Post-ASRC slope. The dotted line shows the unity line 1:1

performing a near task, the accommodative demand (0D) at six meters was $-0.16 \text{ D} \pm 0.02 \text{ D}$. After performing near tasks, a lead of accommodation was evidenced with a mean \pm SD of $-0.37 \text{ D} \pm 0.01 \text{ D}$.

In comparison, the lag of accommodation increased with decreasing viewing distance. A significant difference between the four lighting conditions was only found after performing near tasks at 3D and 5D accommodative demand. At 3D accommodative demand, the lag of accommodation differed significantly between the four lightings ($F_{(3,87)} = 4.26$, $p <$

0.05). The Post hoc Bonferroni test indicated a mean difference of 0.10 D between Light 1 & Light 2 ($p < 0.05$) and a mean difference of 0.14 D between Light 1 & Light 4 ($p < 0.05$). At 5D accommodative demand (20 cm viewing distance), a significant difference was also found between four lighting conditions ($F_{(3,87)} = 7.77$, $p < 0.01$). The post hoc Bonferroni test revealed a mean difference of 0.15 D between Light 1 & Light 4 ($p < 0.05$) and a mean difference of 0.17 D between Light 3 & Light 4 ($p < 0.01$). Light 1 (fluorescent daylight) showed a higher accommodation lag than the other light types.

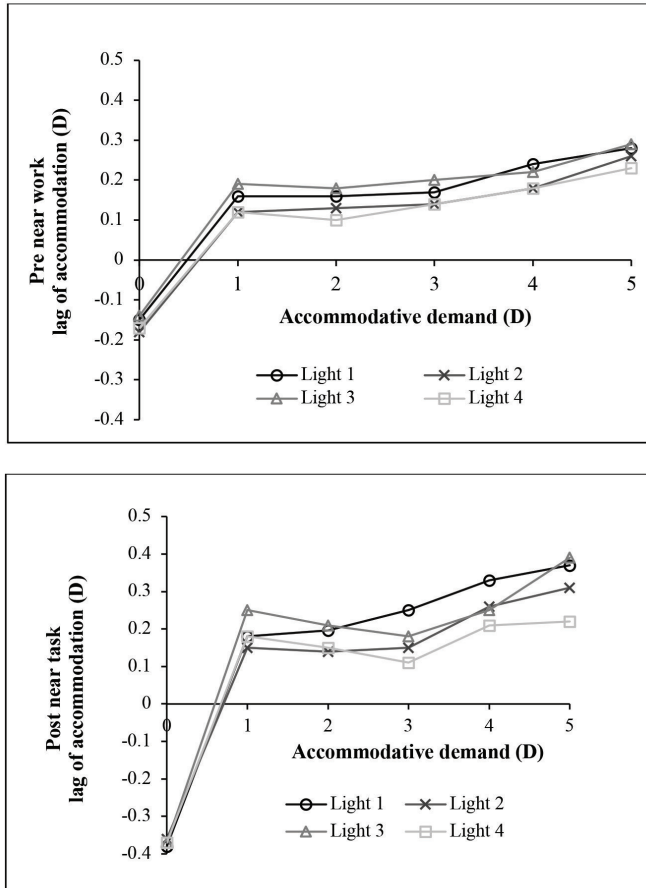


Figure 3: The near task lag of accommodation (D) at different accommodative demands of the 1D target was tested at 100cm, 2D at 50cm, 3D at 0.33cm, 4 D at 0.25cm and 5D at 20cm. Light 1 is fluorescent daylight. Light 2 is Fluorescent warm light. Light 3 is LED Daylight. Light 4 is an LED warm light

The observable ocular responses towards the short exposure duration of near work under the four lightings were noteworthy. Daylight (Light 1 & Light 3) range exhibited more accurate accommodation responses or fewer errors. However, between Light 1 and Light 2, Light 1 (fluorescent daylight) displayed more accommodation lag and twofold flattening of slopes compared to Light 3 (LED daylight). The precision was reduced in both warm lights (Light 2 & 4).

Our study found significant flattening of the ASRC gradient, indicative of accommodative lag and visual fatigue, in a cohort of young myopes following a concentrated near-work task for 30 min at a short working distance. Our finding

agrees with Tosha et al. (2009), who reported accommodative lag following near vision tasks in both myopes and non-myopes. They also self-reported high levels of accommodative lag in those with visual discomfort than those with lower visual discomfort. Symptoms and clinical measures have been linked to the accommodative-vergence synergy resulting from sustained near-point stress (Wajuihian, 2020; 2021)

Elevated light level and violet light exposure have been preventive strategies against myopia progression. Lag of accommodation has been associated with myopia progression due to retinal blur or defocus notion (Nakatsuka et al., 2005; Allen & O’Leary, 2006; Mutti et al.,

2006; Cheng *et al.*, 2008; Manny *et al.*, 2009; Berntsen *et al.*, 2010; Sreenivasan *et al.*, 2011). A high accommodative lag leading to retinal blur might contribute to myopia progression (Mutti *et al.*, 2006; Cheng *et al.*, 2008; Berntsen *et al.*, 2010). Retinal blur is a stimulus for eye growth resulting in axial elongation to clear the blur and place the conjugate image on the retina (Mutti *et al.*, 2006; Cheng *et al.*, 2008; Berntsen *et al.*, 2010). Nevertheless, our findings of fluorescent daylight with the green to red range of visible colour spectrum displayed more accommodation lag and twofold flattening of slopes compared to LED daylight. Violet light range exhibited more accurate accommodation responses or less error. When the light is under the category of warm light, the exactness seems to diminish. The lower illumination level (or dimmer) of warm light than the daylight, both for fluorescent and LED, might also contribute to the reduced accuracy of accommodation. Our findings also suggest that a short wavelength in the spectral power distribution has a more significant influence than a longer wavelength in the warm lighting condition. Outdoor natural lighting (daylight) has been previously suggested as protective against myopia development. However, our study's fluorescent and LED daylights showed greater inaccuracy in the accommodation-near work association than their warm light counterparts. Our findings suggested that artificial daylight might affect myopia differently than natural daylight, although both emitted blue light spectrums. The effect may be a stress indicator for visual stability in the near triad; recent findings reported differences in the amount of blur experienced by different refractive groups at different ages and under different lighting conditions (Chen *et al.*, 2019). Artificial daylight might harm vision and contribute to a higher prevalence of myopia in countries that use daylight in school lighting settings. However, further investigation is required to confirm using longitudinal myopia studies.

Higher accommodative fluctuations were associated with myopia and mesopic conditions. However, this speculation requires further

investigation to confirm. Previous research reports that near visual acuity measurements improve with higher CCT in children and young adults (Navvab, 2002; Berman *et al.*, 2006) and visual discomfort is reduced with higher CCT and LED lighting in young adults (Wang *et al.*, 2015). Our study revealed that LED and fluorescent lighting of a different CCT did not affect the ASRC gradient. ASRC may not be as sensitive as visual acuity measurement to detect the difference.

A higher CCT results in smaller pupil size were observed, improving near visual acuity (Berman *et al.*, 2006). One of the limitations of the present study was lacking data on pupil size. All measurements were conducted under natural pupil size, which raised a question on pupil size's effect on our findings. Using the formula by Charman and Radhakrishnan (Charman & Radhakrishnan, 2009) on the relationship between pupil size and age [pupil = (-0.08 x age) + 7.58], the estimated pupil size of our subjects was approximately 5.80 mm. Charman and Radhakrishnan also investigated the relationship between pupil size and refractive, and they outlined a regression-linear formula between the two parameters [pupil = (-0.03 x mean-sphere errors) + 5.52]. We estimate the variation that might be caused by pupil size in our subjects due to refractive error differences. The estimated pupil size ranged from 5.99 mm to 5.49 mm. This slight variation was unlikely to alter the outcome. The pupil size had been reported to decrease when the demand increased from 0 to 6 D due to near triad. A regression-linear formula could describe the relationship between the two tabulated parameters [pupil = -0.13 (demand) + 5.68]. Using the formula, our study's estimated pupil size at far and near demand was 5.68 mm and 5.16 mm, respectively. Hypothetically, a pupil size of 0.52 mm difference between far and near demand in our subjects might contribute to an accommodation response difference of 0.047 D. A difference of less than 0.05 D due to pupil size was unlikely to affect the original findings. The pupil size difference between the highest and the lowest refractive error was approximately 0.5 mm. Hypothetically, a pupil size of 0.08 mm

difference might contribute to an accommodation response difference. A regression-linear formula could predict the relationship between the two tabulated parameters [pupil = -0.003 (lighting in lux) + 5.40]. Using the formula, our study's estimated pupil size under 259 lux and 324 lux lighting were 4.55 mm and 4.33 mm, respectively. Hypothetically, a pupil size of 0.22 mm difference between max and min lighting in our subjects might contribute to an accommodation response difference of 0.02 D. A difference of less than 0.02 D due to pupil size was unlikely to affect the outcomes. The accommodation variation possibly caused by pupil size in our study (ranging from 0.41 D to 0.39 D) was unlikely to change the conclusion of this study. However, our explanation did not rule out the possible contribution of pupil size to myopia development. Myopia is associated with a close working distance (Rose *et al.*, 2008) near high-intensity work and longer duration (Muhamedagic *et al.*, 2014; Li *et al.*, 2015). ASRC gradient is method dependent. A flatter ASRC gradient was more apparent in young adult myopes using the negative lens series method than the decreasing distance series or positive lens series methods. Smith *et al.* (2015) showed more hyperopic refractive in monkeys exposed to longer wavelengths via red filters. Our study revealed more lag of accommodation after near work with the four investigated lightings. Greater accommodative lag following near work resulted in hyperopic defocus might stimulate myopic growth. Different types of artificial lights affect the accommodation system of the eyes differently. Daylight stimulates more accommodative errors than warm light. A longitudinal prospective refractive study is imperative before a more conclusive stance on light influence on myopia development.

Conclusion

The increment in the accommodative inaccuracy was apparent in all lighting conditions following prolonged close work among the myopic young adults. The types of light (LED versus fluorescent; and warm versus daylight) were not

imperative. This information can be useful for the interior light choice of buildings. However, our study was only limited to short-term exposure. Therefore, the effect of long-term exposure requires further investigation.

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