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# Reduced Monocular Accommodation Abilities with Laptop Usage under Scotopic Ambient Illumination

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**Abstract**
Laptops are widely used even in dark scotopic rooms. This study compares monocular accommodation statuses with laptop usage under three illuminations. Thirty university students read on a laptop for 5 minutes under scotopic, mesopic, and photopic conditions. The monocular amplitude of accommodation, accommodation facility, and accommodation error are measured for each illumination. Repeated measure ANOVA shows a significant difference in the amplitude, facility, and error between different illuminations [$F(1.49, 43.18) = 10.61$, $p<0.001$], [$F(1.65, 36.30) = 6.78$, $p=0.005$] and [$F(2, 56) = 3.65$, $p=0.032$]. Scotopic illumination reduces monocular accommodation abilities with laptop usage.

Keywords: Accommodation abilities; laptop usage; scotopic illumination; photopic illumination


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## 1.0 Introduction

With rapid technological advancement in the current decade, there is a rising trend in using digital devices in the work environment. This relates to the increment in visual problems among digital device users. These devices raise concerns about visual health, including the accommodation system responsible for focusing ability at various distances. People are becoming more reliant on digital devices, which have become part of their daily activities. The commonly used devices are laptops, computers, smartphones, and tablets. Prolonged screen time can have a potential impact not only on ocular health but also on visual accommodation. However, digital devices are not limited to extended use as they are also commonly used for brief duration, such as when checking messages or emails. With the devices having self-illuminating displays, people can use them in ambient illumination, under bright photopic lighting, or even in a dark scotopic room. Most digital device users use laptops and desktops in offices or classes for work and online activities. Thus, this paper investigates the effect of different ambient illuminations on accommodation abilities with laptop usage by comparing monocular accommodation statuses, which are amplitude of accommodation (AA), accommodation facility (AF), and accommodation error (AE) with laptop usage under three different illuminations of photopic, mesopic, and scotopic conditions.


DOI:

**Nomenclature**

| | |
|---|---|
| AA | amplitude of accommodation |
| AF | accommodation facility |
| AE | accommodation error |

## 2.0 Literature Review

*2.1 Accommodation and Digital Device Usage*

The vision system involves visual focusing to ensure the eyes can change focus to see objects at different distances and maintain clear images. This ability is known as accommodation, which also refers to the changes in refractive power to appropriately place the image of objects at the retina for every distance. According to Hinkley et al. (2014), accommodation can be measured using a variety of methods, such as amplitude of accommodation (AA), accommodation facility (AF), and accommodation response. AA determines the strength of accommodation magnitude, while AF describes the flexibility of accommodation. The flexibility of accommodation is vital to ensure rapid focusing changes on accommodation response, such as switching fixation from the laptop or smartphone display to other fixation points or onto the distance (Sheppard & Wolffsohn, 2018). On the other hand, the accommodation error (AE) reveals the accuracy of the accommodation response, which reduces when the error increases.

A recent study discovered that AA and AF differ significantly after smartphone usage (Chikuse et al., 2023). Kim et al. (2020) also notice that accommodation response is affected, causing changes in accommodation function after digital device usage at a near distance for a long time. The changes in accommodation status, including the AA and even in vergence status, such as vergence facility, accommodative convergence, and accommodation ratio, are related to the use of digital devices in prolonged duration of near work (Padavettan et al., 2021). The accommodation and vergence are generally affected by the extended continuous near work on these devices. Continuous smartphone usage for 20 minutes causes a significant change in accommodation status except for negative relative accommodation (Narawi et al., 2020). Moreover, continuous reading using smartphones for 20 minutes can also increase the symptoms of blurred vision and other discomforts such as difficulty refocusing, dry eyes, eyestrain, glare, discomfort, and burning eyes. As various investigations have been conducted to determine the effect of digital devices on accommodation, many researchers have reported similar findings of decreased accommodation ability with near-digital device usage (Allen & Mehta, 2023; Kang et al., 2021; Kim et al., 2020).

Nevertheless, when exploring the digital device effect based on the refractive status, it is discovered that the accommodation response is lagging among mild myopes, with the digital tasks having more significant AE than the printed text task, as opposed to more significant AE in the printed text task than in the digital task among moderate myopes (Liang et al., 2021). In normal eyes with good visual acuity, there is also a change in clinical signs after digital device usage, such as receding near the point of accommodation, increased accommodative lag by 0.8 D, and reduced accommodation facility by 2.29 cpm (Allen & Mehta, 2023). This shows that digital devices have a significant effect on the accommodative system.

*2.2 Illumination and Accommodation*

Illumination also plays a role in accommodation ability. Several studies have demonstrated the influence of different illumination or lighting conditions on the AA and the relationship between ambient illumination and the eye's accommodative response (Okada et al., 2013; Yu et al., 2022). For instance, Okada et al. (2013) have shown that accommodation effort increases in low illumination, while high illumination reduces accommodation effort. This indicates a difference in how the accommodation responds under low illumination than in high illumination. Using different light intensities of 5, 100, 200, 500, 1000, 2000, and 3000 lux, Yu et al. (2022) discovered that accommodation response is higher when induced by different light intensities of dynamic lighting than in static light conditions. The dynamic lighting level between 5 and 3000 lux can induce a change in the AA of 1.01 D. They also postulate that a remarkably high illumination may cause vision fatigue and harm the ocular fundus.

Furthermore, the retinal illuminance also decreases the AA based on the stimulus range commonly encountered with reading, showing that the eye's ability to accommodate or respond to different illumination is not solely dependent on shifting pupil size (Lara et al., 2020). As variation in light exposure contributes to the constriction and dilation of the pupil, their study reveals that low photopic light levels, commonly used for reading, can also lead to a reduction in the AA. Lowered light levels can worsen the age-related deterioration in the AA. Thus, optical aids become necessary at the age at which the accommodation is physiologically declined, such as in presbyopia.

As digital devices such as laptops consist of self-illuminating displays, the devices can provide their light source. People can use these devices under varying ambient lighting, whether under bright photopic illumination or even in a dark scotopic room. Different ambient illuminations may influence accommodation abilities to maintain focus with laptop usage. This led to the question of how different ambient illuminations of photopic, mesopic, and scotopic conditions affect the accommodation parameters with laptop usage. By investigating the monocular accommodation ability of AA, AF, and AE with laptop usage under three different illuminations of photopic, mesopic, and scotopic conditions, the effect of different illuminations on these monocular accommodation parameters even with a brief duration of laptop usage can be ascertained.

## 3.0 Methodology

*3.1 Subject Selection and Screening Procedures*

This study involves an experimental cross-sectional approach to understand the effect of different ambient illuminations on monocular accommodation statuses with laptop usage. The sample size for this study is calculated using the following sample size calculation formula.

$$n = [(z \ x \ \sigma) \div \Delta]^2$$

The calculation uses the value of 0.64 for σ of standard deviation (SD) based on previous research (Jeng et al., 2014), with z at 1.96 for 95% confidence and precision ∆ of 0.25. Based on the calculation, a sample size of 25 is required. However, considering a 20% attrition rate in this study that involves repeating standardized measurements under different ambient illuminations, this study involves 30 subjects. A convenient sampling method is employed to ensure subjects are selected based on the inclusion of best-corrected distance visual acuity of 6/6 or better and near visual acuity of N6 or better, with the age ranges between 18 and 26 years old. Any subjects with a history of binocular vision problems, ocular diseases, pathologies, or systemic diseases are excluded from this study. All subjects are either emmetropic or have mild myopia refractive correction.

Comprehensive history-taking is done to ascertain any history of binocular vision problems, ocular diseases or pathologies, eye injuries, trauma or surgery, and systemic diseases. Screening procedures are conducted to ensure the suitability of subjects by measuring visual acuity, cover test, near point of convergence, lateral heterophoria, and accommodative convergence (AC/A) ratio. Habitual visual acuity is measured using the Snellen Visual Acuity Chart at 6 m and near reading chart at 40 cm from the subjects' eyes. The unilateral and alternating cover tests check for any ocular deviation at 6 m and 40 cm. The measurement for lateral heterophoria is done using the Maddox rod technique at 6 m and 40 cm. Near point of convergence is measured three times to determine the ability of subjects to converge. The accommodative convergence (AC/A) ratio is calculated using the value of lateral heterophoria and interpupillary distance to confirm that the ratio value is within the normal range of 4±2:1.

*3.2 Experimental Setting and Data Measurement*

Ambient illumination consists of three conditions: dark illumination of 1 lux, dimmed illumination of 30 lux, and normal bright illumination of 300 lux. These three different illuminations correspond to scotopic, mesopic, and photopic vision. The ambient illumination is set in a standardized examination room measuring 7.5 m in length, 1.2 m in width, and 3 m in height. All four walls cover The room with black curtains to minimize light reflection. The illumination source in the room is from ceiling-mounted fluorescent lights, which are entirely switched on for 300 lux photopic condition and partially switched off for dimmed 30 lux mesopic condition. The fluorescent lights are switched off for 1 lux scotopic condition with the ambient light from an auxiliary lamp positioned behind the subjects.

Data on accommodation ability measurements consist of the amplitude of accommodation, accommodation facility, and accommodation response error, and all parameters are taken monocularly on the right eye at a near distance. The monocular amplitude of accommodation is measured using the push-up method with the Royal Air Force (RAF) rule to obtain the maximal accommodative magnitude. The monocular accommodation facility is calculated using a ±2.00D lens flipper while clearing the N6 target at 40 cm. The monocular accommodation response error is measured objectively at 40 cm through an open-field WAM-5500 Grand-Seiko auto refractometer based on calculating accommodation stimulus demand (2.5 D) and subtracting accommodation response. These accommodation ability measurements are conducted under the three ambient illumination conditions.

A Hewlett Packard laptop with dimensions of 34 x 24 x 2.37 cm in width, length, and thickness, having a display resolution of 1366 x 768 pixels, is used in this study. The subjects are seated in front of the reading text on the laptop at 40 cm. The laptop display's brightness is set at 50% based on the display setting. The reading material consists of text from an online story about Alice in Wonderland, with black letters displayed on a white background and font size corresponding to N6 visual acuity. The subjects must read on the laptop display for 5 minutes, and the data measurements are taken immediately after laptop usage is completed. This 5-minute duration is a limitation in this study to properly show the effect of prolonged continuous near work. However, this duration can still depict a brief influence of near work on the accommodation system. The measurements are repeated for different ambient illuminations. Before proceeding to data measurement, the subjects are rested for 5 minutes in a dark room without any stimulus, which acts as a washout period.

## 4.0 Findings

Of the 30 subjects in this study, 15 (50%) are female and 15 (50%) are male. Their mean ± standard deviation age is 22.70 years (± 1.579). The first monocular accommodation ability is the monocular amplitude of accommodation (AA), which is recorded in dioptre (D). The mean ± standard deviation of monocular AA with laptop usage under photopic, mesopic, and scotopic is 9.73 (± 2.021) D, 9.34 (± 1.931) D, and 8.39 (± 2.299) D, respectively, as seen in Table 1. Based on the Shapiro-Wilk test, the p-value of monocular AA with laptop usage under the photopic is 0.79, under the mesopic is 0.98, and under the scotopic is 0.341, respectively, indicating normally distributed data ($p>0.05$). Based on repeated measure ANOVA, the effect of illuminances on monocular AA with laptop usage is significant [$F$ (1.49, 43.18) = 10.61, $p<0.001$]. Post-hoc pairwise comparison with a Bonferroni adjustment indicates no significant difference between photopic and mesopic, p = 0.165. However, monocular AA with laptop usage is significantly different under photopic and scotopic (p = 0.001) and between mesopic and scotopic (p = 0.029).

Table 1. Mean and standard deviation of monocular accommodation abilities under three different illuminance

| Parameter of accommodation abilities | Photopic Mean (D) ± SD | Mesopic Mean (D) ± SD | Scotopic Mean (D) ± SD |
|---|---|---|---|
| Monocular AA in diopter (D) | 9.73 (± 2.021) | 9.34 (± 1.931) | 8.39 (± 2.299) |
| Monocular AF in cycles per minute (cpm) | 13.87 (± 4.674) | 12.60 (± 5.345) | 10.52 (± 4.44) |
| Monocular AE in diopter (D) | 0.72 (± 0.416) | 0.66 (± 0.451) | 0.87 (± 0.394) |

The next monocular accommodation ability is the monocular accommodative facility (AF), and the measurement is recorded in cycles per minute (cpm). Table 1 also shows the mean ± SD of monocular AF with laptop usage under photopic, mesopic, and scotopic, which are 13.87 (± 4.674) cpm, 12.60 (± 5.345) cpm, and 10.52 (± 4.44) cpm, respectively. All monocular AF data are usually distributed based on the Shapiro-Wilk test, with p = 0.164 under the photopic, p = 0.539 under the mesopic, and p = 0.16 under the scotopic. Based on repeated measure ANOVA, the effect of illuminances on monocular AF with laptop usage is significant [F (1.65, 36.30) = 6.78, p = 0.005]. Post-hoc pairwise comparison with a Bonferroni adjustment indicates a significant difference in monocular AF between photopic and scotopic (p = 0.013). There is also a significant difference in monocular AF between mesopic and scotopic (p = 0.01) but no significant difference between photopic and mesopic (p = 0.667).

The last monocular accommodation ability is monocular accommodation error (AE), with the measurement recorded in dioptre (D). As depicted in Table 1, the mean ± SD of monocular AE with laptop usage under photopic, mesopic, and scotopic are 0.72 (± 0.416) D, 0.66 (± 0.451) D, and 0.87 (± 0.394) D, respectively. All monocular AE data are normally distributed using the Shapiro-Wilk test: photopic (p = 0.136), mesopic (p = 0.051), and scotopic (p = 0.264). Based on repeated measure ANOVA, the effect of illuminances on monocular AE with laptop usage is significant [F (2, 56) = 3.65, p = 0.032]. Post-hoc pairwise comparison with a Bonferroni adjustment indicates a significant difference in monocular AE between under mesopic and scotopic (p = 0.02). However, monocular AE with laptop usage is not significantly different between photopic and mesopic (p = 1.00) and between photopic and scotopic (p = 0.261).

## 5.0 Discussion

Our study discovers that monocular amplitude of accommodation (AA) under photopic and scotopic illumination using a laptop shows a significant difference, even for 5-minute laptop usage. However, there is no significant difference in the monocular AA with laptop usage under photopic and mesopic illumination. These findings can be attributed to retinal illuminance's influence on the eye's ability to focus (Lara et al., 2020), which seems to be greatly aggravated under very low illumination of dark scotopic conditions. Although the previous study shows that the AA decreases with retinal illuminance even at low photopic lighting, this effect is more noticeable when illumination differs between mesopic and scotopic illuminations, as found in our study. The reduced retinal illumination makes it harder to detect the out-of-focus blurring. Factors like age and pupillary diameter also affect AA. It has been reported that the use of digital devices decreases AA in both young adults and older people (Kubota et al., 2020). However, a study by Padavettan et al. (2021) reveals a robust accommodative reserve in young adults, reducing the probability of enormous variation in the accommodation ability across average university students in our study since the subjects' age is closely matched. As for pupillary diameter, under photopic illumination, the pupil constricts, which reduces the demand for accommodation in the eyes to generate focusing of a clear image. In contrast, under scotopic illumination, the pupil dilates and increases the demand for the accommodative system, leading to a subsequent reduction in the AA.

Nevertheless, a previous study shows no significant difference between AA after visual display unit (VDU) usage and different illuminations (Majumder & Zafirah Zaimi, 2017). In their research, the method used to measure AA differs from the minus lens method. In contrast, our study uses the push-up measurement method to obtain the physically proximal magnitude of focusing ability. In addition, the illumination level also differs as they investigate 5 lux, 17 lux, and 23 lux, whereas this current study used 1 lux for scotopic, 30 lux for mesopic, and 300 lux for photopic. In addition, Devenier et al. (2021) also uncovered a significant difference between AA measured between the digital display target and the paper-based target, with a higher median of AA with the digital display. Even though the previous study used an iPad or tablet as a digital display target, their findings imply that the near working distance is slightly closer than the paper-based target, even when the text used was similar in size and font.

In this recent finding of laptop usage, monocular AF under photopic and scotopic conditions shows a significant difference. Similarly, monocular AF between the mesopic and scotopic conditions significantly differs. The significant changes in monocular AF after laptop usage can be attributed to the accommodation system's visual stimulation and environmental lighting conditions. This finding also highlights the importance of considering illuminance levels during laptop use. Continuous near-work can affect the accommodation system, leading to changes in parameters such as AF (Ashwini et al., 2023). However, their study observes no significant difference in monocular AF after playing games on a laptop and mobile for 1 hour. This can be because their lighting could be more varied compared to our study, which uses three different illumination conditions. Their study contrasts with another study by Narawi et al. (2020), which discovered a significant difference in monocular AF after using a digital device or smartphone for 20 minutes. Nevertheless, a brief duration of laptop usage in our recent study can also produce a significant difference in monocular AF, especially under dark scotopic illumination.

When comparing the laptop's usage under different illuminances, the result shows a significant difference in monocular AE between the laptop usage under mesopic and scotopic. This supports the previous study that the change in light intensity positively correlates with accommodation ability, with a more pronounced accommodation response (Yu et al., 2022). Although they only find the difference under dynamic lighting, but not static lighting, the monocular AE describes the accurate focusing position of the eye. The significant difference in accommodation response after laptop usage under dim and dark illumination can be due to pupil diameter variations affecting the accommodation's focus position and convergence (Okada et al., 2013). In the mesopic illumination, the pupil dilates to allow more light to enter the eye. Even though this helps to see in low lighting, it also reduces the depth of field, making it harder to maintain a sharp focus and increasing accommodation demand. As the laptop in our study consists of a high-resolution display, the spatial resolution of the display used for viewing content can impact the linear change in accommodation response (Yano et al., 2018). This may also accentuate the effect of dark scotopic on accommodation ability with laptop usage.

## 6.0 Conclusion & Recommendations

It can be concluded that dark scotopic ambient illumination significantly reduces monocular accommodation abilities with laptop usage, even briefly. The study's findings contribute to the substantiated understanding of the environmental risk of low lighting on vision systems. Inadequate lighting harms the eye, leading to various eye problems such as myopia and eyestrain. Nevertheless, this study is limited by the 5-minute duration, less than the duration of digital near work among many people. The subjects are also limited among young adults, in which older adults have more significantly declined accommodation ability. Thus, it is recommended that tasks be longer and age ranges are more comprehensive to improve future studies on accommodation systems. Although this study reveals the negative effect of laptop usage under low lighting on monocular accommodation status, especially among normal young subjects, future studies can evaluate binocular accommodation status and vergence system to properly investigate the vision system's natural viewing.

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## Paper Contribution to Related Field of Study

Dark ambient conditions aggravate the ocular focusing system, making it more difficult to see clearly. This relates to the vision health environment, especially in advising the public on the proper setting of daily activities. Although the laptop display is self-illuminating and visible under different illuminations, proper lighting should be used even for brief laptop usage.

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