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Impact of Screen Brightness on Static and Dynamic Aspects of Accommodation among Digital Eye Strain Subjects

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Abstract:

Purpose: This study examined the impact of screen brightness on an OLED display, investigating the accommodation and pupillary responses of individuals with pre-existing digital eye strain. The hypothesis was that screen brightness would influence the dynamics of accommodation and pupillary response.

Design: Prospective, quasi-experimental study

Methods: This study was conducted in a single hospital setting. A total of 324 patients were screened for digital eye strain using a validated questionnaire. Forty-six participants who met the inclusion criteria were enrolled, comprising young subjects with no history of binocular vision anomalies or ocular problems contributing to binocular vision or digital eye strain. The dynamic accommodative response and pupillary motility of the participants dominant eye were continuously measured using an automatic refractometer as they read text passages under three different screen brightness settings: 200 lux, four hundred lux, and six hundred lux, each for two minutes. The study was conducted under preferred four hundred lux office room illumination, with text size kept constant at 12-point size and 100% letter contrast. Participants viewed the text from a fixed distance of 50 cm.

Results: Repeated-measures ANOVA revealed that screen brightness settings significantly affected both pupillary dynamics and accommodation response, with statistical significance at $p < .001$. Specifically, a screen brightness of four hundred lux, equal to the room illumination, was associated with acceptable accommodation latencies and ideal pupil responses. In contrast, the 200-lux screen brightness setting resulted in higher accommodation latencies, while the 600-lux screen brightness setting led to lower accommodation latencies but towards the lead of accommodation.

Conclusion: Maintaining adequate brightness settings on digital displays may improve eye function for people with digital eye strain. A screen brightness equal to the surrounding ambient illumination can help the eye to focus and minimize the need for constant adjustment. This may reduce their symptoms of digital eye strain, as accommodation lag is a major cause of this condition. Low screen brightness increases eye strain because it results in higher accommodation lag. Conversely, high screen brightness may cause a lead of accommodation and exacerbate digital eye strain symptoms. Optimizing the screen brightness to match the ambient illumination while working can be an important way to manage digital eye strain.

Keywords: Digital eye strain, Computer vision syndrome, Accommodation, Pupillary Dynamics, Screen Brightness.

1. Introduction

The prevalence of digital eye strain, also known as computer vision syndrome, is exceptionally high, affecting over 50% of computer users globally. This widespread issue is a significant public health concern as digital device usage continues to grow in both professional and personal spheres. (Sheppard & Wolffsohn, 2018) Prevalence rates have varied widely, ranging from 5% to 65% prior to the pandemic, and alarmingly increased to 50-60% in children during the COVID-19 pandemic. (Trott et al., 2022)(Nagata et al., 2022) The incidence of digital eye strain in India has fluctuated significantly, largely due to the dramatic effects of the COVID-19 pandemic. When remote work and online education became widespread, the incidence of digital eye strain in India increased dramatically, estimated at around 50-60% in children and adolescents. (Kelkar et al., 2022)(Mohan et al., 2021)(Wadhwani et al., 2022)(Hussaindeen et al., 2020)(Bhattacharya et al., 2020)(Agarwal et al., 2021) This sharp increase reflects the surge in digital device use for work, school, and entertainment during the pandemic, exacerbating the country's existing digital eye strain problem. (Kaur et al., 2022) Overall, these data emphasize the urgent need for eye care professionals to address the increasing incidence of digital eye strain, particularly in younger populations, as the symptoms can be frequent, persistent, and potentially impact educational and occupational performance.

Digital eye strain, also known as computer vision syndrome, encompasses a set of visual and ocular symptoms associated with frequent and extended use of digital devices such as computers, tablets, and smartphones. These symptoms may include eye strain, headaches, blurred vision, dry and irritated eyes, and other discomforts experienced during and after prolonged screen engagement.(Mylona et al., 2023)(Kaur et al., 2022)(Sheppard & Wolffsohn, 2018)(Dessie et al., 2018)(Blehm et al., 2005)(Rosenfield, 2011)The growing reliance on digital technologies highlights the need to understand and address the factors contributing to digital eye strain. One key factor is lag/lead of accommodation, which refers to the difference between the eye's actual focus and the optimal focus required for a given viewing distance.(Tosha et al., 2009)(Devenier et al., 2021)(Shahri et al., 2021)(Moulakaki et al., 2017)(Collins et al., 1994)Prolonged screen time can lead to accommodation fatigue, which in turn may result in visual discomfort symptoms.(Al-Atawi, 2023)(Parihar et al., 2016)Proper accommodation and the pupillary light reflex are essential for clear and comfortable vision, and disruption of these processes is a central mechanism underlying digital eye strain.(Sheedy, 2007)

Accommodation, which is the eye's ability to adjust focus for clear vision at varying distances, plays a crucial role in the development of digital eye strain.(Coles-Brennan et al., 2019) Prolonged close-up work, such as viewing digital screens, requires sustained accommodation, potentially leading to accommodation fatigue and spasm. (Collier & Rosenfield, 2011) Accommodation latency, the difference between the eye's actual and optimal focus, is a key physiological factor contributing to digital eye fatigue, especially during prolonged near-work tasks on screens. (Tosha et al., 2009) (Saito et al., 1994) (Sheedy, 2007) This phenomenon occurs when the eye's focus cannot fully reach the near object, causing visual discomfort and strain. (Jaschinski, 1991) Failure to accommodate adequately can exacerbate symptoms related to visual disturbances, often associated with adaptation errors and fatigue from prolonged close work. Furthermore, accommodative fatigue, characterized by a decreasing ability to accurately focus over time, can further contribute to this stress. (Blehm et al., 2005) (Rosenfield, 2011) (Kaur et al., 2022) As the eye struggles to maintain focus, individuals may experience blurred vision and eye strain, indicating adaptive dysfunction. Additionally, adaptation latency, the delay in the eye's response to changes in focus, is important for understanding how these factors affect visual comfort during prolonged screen use. (Freivalds et al., 1989) (Campbell et al., 1959)

Prior research has highlighted several notable findings on the impact of digital device use on accommodation. Studies indicate that prolonged close-up work, particularly with digital screens, can impact accommodation and visual comfort. (Allen & Mehta, 2023) (Krupinski & Berbaum, 2009) (Devenier et al., 2021) (Shahri et al., 2021) (Jaiswal et al., 2019) Additionally, evidence suggests that viewing distance and font size on digital displays may affect accommodation and contribute to digital eye strain symptoms. (Bababekova et al., 2011) Previous studies have also shown that higher screen resolution can reduce eye fatigue and improve visual comfort, potentially by diminishing the strain on the adaptive visual system. (Collins et al., 1994) (Miyao et al., 1989) (Hynes et al., 2022) .The effect of display color on accommodation remains unclear, as few studies have detected differences in accommodative responses to changing color temperature. (Jiménez et al., 2020) (Charman & Tucker, 1978) .Shorter viewing distances are associated with increased demands for accommodation, which may contribute to eye strain and fatigue. (JASCHTNSKI-KRUZA, 1990) Existing studies have been limited by factors such as lack of randomization, objective assessment, target age group, diagnostic criteria, and longitudinal data.

This study investigates the impact of OLED display screen brightness on the accommodative responses of individuals experiencing digital eye strain. While prior research has examined the association between various digital device characteristics and accommodation, additional investigations are needed to enhance visual ergonomics and mitigate digital eye strain or computer vision syndrome. By assessing the influence of screen brightness on accommodative lag in the diseased population, the study offers valuable insights to inform practical solutions addressing the escalating issue of digital eye strain.

2. Methods

2.1 Participants and ethical approval

A total of 324 individuals were screened using the validated Computer Vision Syndrome Questionnaire (Seguí-Crespo et al., 2015), and 46 emmetropic participants who met the inclusion criteria were enrolled in this non-randomized clinical study. The mean age of the participants was 24.5 ± 3.9 years. All participants underwent a preliminary eye examination to verify the following eligibility criteria: reported symptoms of digital eye strain, had emmetropia in each eye, had best-corrected visual acuity of 0.00 log MAR or better in both eyes, had no systemic disease or recent drug treatment, had no history of refractive surgery, orthokeratology, strabismus, amblyopia, or binocular vision anomalies, and had abstained from alcohol consumption and obtained at least 7 hours of sleep prior to the study. The study protocol was approved by the Institutional Review Board, identified as SEH/BLR/EC/2023/I02, in accordance with the principles of the Declaration of Helsinki. A non-probability sampling design was employed, and participants were recruited from those visiting the hospital, who provided informed consent.

The sample size was calculated using the formula shown in **Figure 1**, which is commonly used to determine the sample size for experimental research studies with repeated measures. After conducting a pilot study on ten subjects, the standard deviation of the mean accommodative response was 0.36 D, with an effect size of 0.30, a correlation factor of 0.50, a significance level of 0.05, and a power of 0.80. Based on these parameters, the required sample size was calculated to be forty-six participants.

Figure 1: Sample Size formulae used to calculate the final sample.

$$n = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \cdot 2 \cdot \sigma^2}{\Delta^2 \cdot (1 - \rho)}$$

2.2 Experimental conditions

This study examined the accommodative response behavior and pupillary dynamics of individuals as they read a 2-minute text passage on an OLED screen placed 50 cm away, under three distinct screen brightness levels: 200 lux, 400 lux, and 600 lux (Shieh & Lee, 2007). The room illumination was maintained constant at four hundred lux, as verified using a calibrated lux meter. The chosen viewing distance of 50 cm aligns with previous research indicating this as a comfortable distance for digital display users. The experiment utilized Verdana font as recommended by Sheedy, Smith, and Hayes (Sheedy et al., 2005). All measurements were conducted on a 14-inch OLED panel with a resolution of 2800x1800, at 50 cm from the participants' eyes. Following established research techniques, the monitor was positioned at a 105-degree angle, resulting in a 15-degree viewing angle with the participants' eyes slightly above the screen center. A WAM-5500 open-field autorefractometer was employed under binocular conditions to continuously record pupillary dynamics and accommodative response in high-speed mode. This equipment measured the accommodative response and pupil size at a frequency of 5 Hz, with an accuracy of 0.01 D and 0.1 mm, respectively (Sheppard & Davies, 2010).

2.3 Assessment of accommodative response and pupillary dynamics

Initially, the WAM-5500 autorefractometer was used to measure the participants' distance monocular refraction in static mode, which was later used to calculate the accommodation lag in the study. Participants read a 2-minute text passage displayed on a laptop screen placed 50 cm away, with the font size set at 12 points. This procedure was repeated under three different screen brightness conditions: 200 lux, four hundred lux, and six hundred lux, presented in a random order. Between each experimental condition, a 5-minute break was provided as washout period for previous stimulus exposure. Continuous measurements of the participants' dominant eye were recorded (Lin et al., 2016). The accommodation response data were analyzed to determine the accommodation response. The mean accommodative response to each stimulus was calculated by subtracting the distance baseline refractive state from the mean accommodative response observed over the 2-minute reading period. Data points exhibiting more than three standard deviations of variation, likely due to eye blinks or registration errors, were removed in accordance with previous research recommendations (Jiménez et al., 2020). The accommodation latency was then calculated by subtracting the mean accommodation response from the demand.

2.4 Procedure

During the initial appointment, an optometrist evaluated all participants, ensuring they completed the Computer Vision Syndrome Questionnaire and had their binocular vision parameters, such as near point convergence, amplitude of accommodation, phoria for distance and near, extra ocular motility, Worth Four Dot test, and Titmus fly test, assessed to confirm they met the inclusion criteria and had no binocular vision anomalies. On the second visit, the WAM-5500 open-field autorefractometer was used to measure the participants' baseline distance refraction. Participants were then given the opportunity to read the provided text and familiarize themselves with the laptop setup, scrolling through the text at their own pace and reading it aloud. For the second visit, all participants attended at the same scheduled time, with a standard deviation of one hour. The WAM-5500 autorefractometer was employed in high-speed mode to continuously assess the participants' pupillary dynamics and accommodation response while they read the 2-minute text aloud.

2.5 Statistical analysis

The normality of the data and the equality of variances were assessed using the Shapiro-Wilk test. Repeated-measures ANOVA was utilized to compare the accommodative response, pupil size across the different screen brightness conditions. Additionally, post-hoc analysis with Bonferroni correction was conducted to examine the statistical significance of the differences between the various screen brightness settings. All statistical analyses were performed using MS-Excel and a p-value of less than 0.05 was considered statistically significant.

3.Results

The results revealed a statistically significant difference in the overall accommodative response among the three screen brightness conditions, with $F = 31.2$, $p < .001$, and $\eta 2p= 0.59$. As shown in **Figure 2**, the 200-lux screen brightness exhibited the lowest mean accommodative response of 1.77 ± 0.51 D for a 2.00 DS accommodation demand. Conversely, the accommodation response was highest for the 600 Lux screen brightness, with a mean of 1.93 ± 0.53 D, followed by the 400 Lux screen brightness at 1.87 ± 0.55 D. The post-hoc analysis with Bonferroni correction indicated that the accommodation response for the 200-lux screen brightness was statistically significantly different from the 400 Lux and 600 Lux screen brightness conditions, with p=0.01.

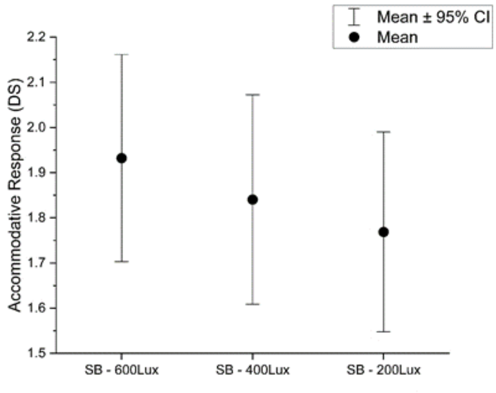

Figure 2: Accommodation Response for Various Screen brightness conditions

Table 1 provides a detailed summary of the accommodation response across the different screen brightness settings, displaying the mean and standard deviation for each screen brightness setting.

Table I Accommodation Response For Various Screen Brighness Settings

Serial Number	Screen Brightness (Lux)	Accommodative response (Mean ± SD)
1	600	1.93 ± 0.53 D
2	400	1.87 ± 0.55 D
3	200	1.77 ± 0.51 D

The study found a statistically significant difference in accommodation lag among the three different screen brightness settings, with F = 31.2, $p < .001$, and η2p = 0.59. Accommodation lag was inversely related to screen brightness. The 200-lux screen brightness had the highest lag of 0.23 ± 0.51 D, followed by the 400-lux screen brightness at 0.16 ± 0.55 D, and the 600-lux screen brightness had the lowest lag of accommodation at 0.07 ± 0.53 D, as shown in Figure 3. Post-hoc analysis revealed that the 200-lux screen brightness had significantly greater accommodation lag compared to the four hundred lux and six hundred lux screen brightness conditions.

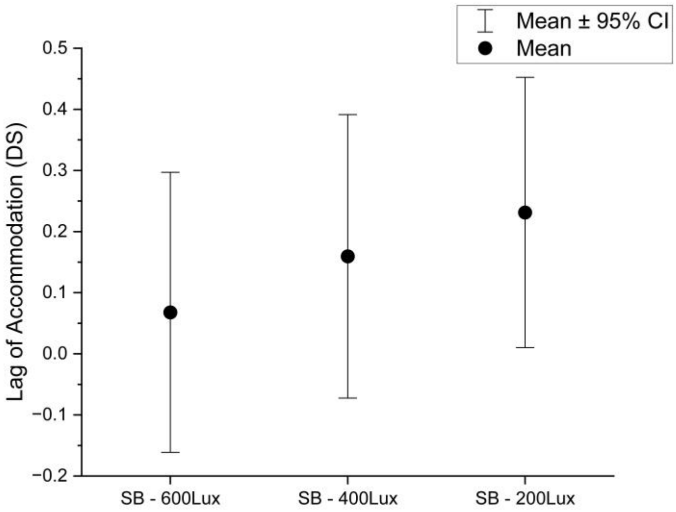

Figure 3: Lag of Accommodation for Various Screen brightness conditions

Table 2 provides the detailed mean and standard deviation of accommodation lag for each screen brightness settings.

Table 2 Lag Of Accommodation For Various Screen Brighness Settings

Serial Number	Screen Brightness (Lux)	Lag of Accommodation (Mean ± SD)
1	600	0.07 ± 0.53 D
2	400	0.16 ± 0.55 D
3	200	0.23 ± 0.51 D

The overall pupil response differed significantly among the three different screen brightness levels, as indicated by the repeated measures ANOVA with F = 42.09, p < .001, and η2p = 0.66. As shown in Figure 4, the mean pupil size was 2.89 ± 0.22 mm for the 600 Lux screen brightness, 3.12 ± 0.30 mm for the 400 Lux screen brightness, and 3.39 ± 0.36 mm for the 200 Lux screen brightness. Post-hoc analysis with Bonferroni correction revealed that the pupil size for the two hundred Lux screen brightness was significantly different from the four hundred Lux and six hundred Lux screen brightness conditions.

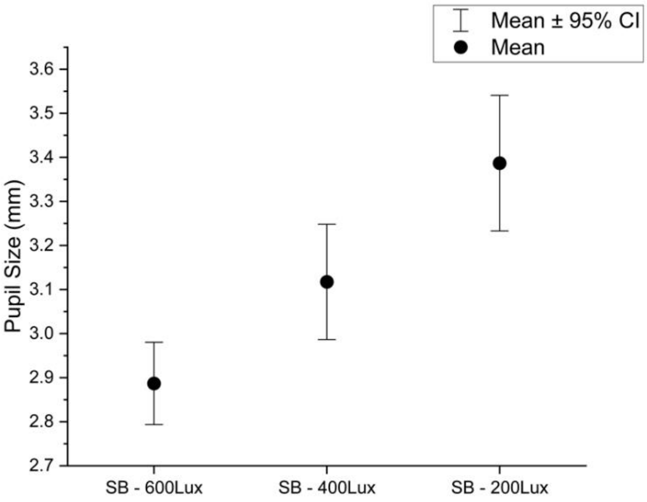

Figure 4: Pupil Size in mm for Various Screen brightness conditions

Table 3 provides the detailed mean and standard deviation of pupil size for each screen brightness settings.

Table 3 Pupil Size In Mm For Various Screen Brighness Settings

Serial Number	Screen Brightness (Lux)	Pupil Size (Mean ± SD)
1	600	2.89 ± 0.22 mm
2	400	3.12 ± 0.30 mm
3	200	3.39 ± 0.36 mm

4. Discussion

The findings demonstrate that the brightness of digital screens profoundly affects the dynamic accommodation and pupillary responses of users during reading tasks. Higher screen brightness, such as six hundred lux caused lead of accommodative response, while lower brightness levels compared to ambient illumination resulted in greater accommodative lag. This suggests that both excessively bright and overly dim screen settings can impair the eyes' ability to focus effectively, potentially exacerbating visual strain associated with prolonged close-up work. The findings highlight the importance of screen brightness as a key factor in digital eye strain, a condition characterized by eye discomfort after prolonged screen use. Increased screen brightness can lead to glare, causing discomfort and making the eyes work harder to focus, which increases strain on the accommodative mechanisms. (Agarwal et al., 2013)Conversely, low screen brightness, especially in bright environments, forces the eyes to adjust to low-contrast visuals, making it harder to read and focus, thus increasing strain. Optimal brightness levels that match the ambient light reduce the need for frequent adjustments in focus and help minimize eye fatigue.

The current study indicates that higher screen brightness on digital displays is associated with lead of accommodation, which can contribute to digital eye strain. Conversely, the 200-lux screen brightness exhibited the highest accommodation lag, which can also contribute to digital eye strain. In contrast, the 400-lux screen brightness showed an acceptable level of lag, enabling better focus during prolonged near visual display terminal tasks. This suggests that screen brightness equal to ambient room illumination is optimal, as it enables better focusing ability and may reduce digital eye strain symptoms caused by increased accommodation lag.

The findings demonstrate an inverse relationship between screen brightness and pupil dynamics. Brighter displays were associated with smaller pupils, which can reduce light entry and contribute to visual fatigue during extended screen use. Conversely, dimmer screens were linked to larger pupils, potentially impairing depth of focus and text clarity, thereby increasing eye strain. Research suggests the optimal pupil size for visual tasks is around 2-3 mm, as deviations in either direction can impact visual performance and exacerbate digital eye strain. (Taptagaporn & Saito, 1990) The current study indicates that screen brightness matching ambient illumination resulted in an optimal pupil size, underscoring the importance of optimizing screen settings to mitigate visual fatigue. Understanding the relationship between pupil size dynamics, visual fatigue, and arousal can inform better screen usage practices and interface designs to enhance user comfort. (Xie et al., 2021)(Chen et al., 2022)(Koo et al., 2018)(Mathôt & Ivanov, 2019) Smaller pupils may restrict light entry, amplifying visual fatigue during prolonged screen reading, as corroborated by prior studies. (Mathôt et al., 2023)(Ebitz & Moore, 2019) Leveraging strategies like dark mode and optimizing luminance contrast can help address the visual strain associated with smaller pupils induced by screen settings and extended use.

This study provides valuable insights into the impact of screen brightness on visual accommodation, but several key limitations should be acknowledged. First, the study examined only three specific screen brightness levels, and exploring a wider range of settings, including varied ambient illumination, may reveal distinct effects on accommodative and pupillary responses. Future research should expand the scope to include additional factors like screen size, viewing distance, and display filters, as these may elicit different visual responses. Additionally, the 2-minute reading task may be insufficient to capture long-term effects of screen brightness on visual fatigue and strain and increasing the task duration could offer further insights. The study's limitation to emmetropic participants is also noteworthy, as individuals with different refractive errors may exhibit varied accommodative and pupillary dynamics and examining a more diverse range of refractive groups could clarify the complex interplay between screen brightness and visual characteristics.

5.Conclusion

Overall, the findings demonstrate that optimal screen brightness matching ambient illumination can significantly improve visual accommodation, enhance user comfort, and reduce fatigue during prolonged digital device use, underscoring the importance of screen brightness optimization as a practical strategy to mitigate digital eye strain. Further research across a wider range of screen and lighting conditions, as well as diverse refractive groups, will expand understanding and guide the development of more visually comfortable digital displays.

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