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Impact of Font Size on Static and Dynamic Aspects of Accommodation among Digital Eye Strain Subjects

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Purpose: This study investigated the short-term effects of text size on an OLED display on the accommodation and pupillary responses of individuals with pre-existing digital eye strain. The hypothesis was that text size would affect the dynamics of accommodation and pupillary response.
Design: Prospective Qasi-experimental study (non-randomized clinical trial)
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, including having no history of digital eye strain, being young, and having no 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 of three different font sizes, each for two minutes. The study was conducted under normal office lighting conditions of 400 lux, with screen brightness maintained at 400 lux and 100% letter contrast. Participants viewed the text from a fixed distance of 50 cm.
Results: Repeated-measures ANOVA was used to examine whether accommodation response and pupillary response differed across the three different font sizes. Results showed that font size significantly affected both pupillary dynamics and accommodation response, with statistical significance at $p < .001$. Specifically, larger font sizes were associated with shorter accommodation latencies and better pupil responses, while the smaller font size of 12 points resulted in higher accommodation latencies and poorer pupil responses.
Conclusion: Using larger font sizes on digital displays may improve eye function for people with digital eye strain. This may reduce their symptoms, as accommodation lag is a major cause of eye strain. Smaller text sizes increase eye strain because accommodation lag is worse with smaller fonts. Adjusting font size is an important way to manage digital eye strain.

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

1. Introduction

The prevalence of digital eye strain, also known as computer vision syndrome, is exceptionally high, affecting more than 50% of computer users globally. This widespread problem is a significant public health concern as the use of digital devices continues to grow in both the professional and personal spheres.[1] Prevalence rates have varied widely, ranging from 5% to 65% in the pre-pandemic period, and alarmingly increased to 50–60% in children during the COVID-19 pandemic.[2,3]The incidence of digital eye strain in India has fluctuated significantly, especially due to the dramatic effects of the COVID-19 pandemic. During the 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.[4–9] This sharp increase reflects the surge in use of digital devices for work, school and entertainment during the pandemic, exacerbating the country's existing digital eye strain problem.[10]Overall, these data support the urgent need for eye care professionals to address the increasing incidence of digital eye strain, particularly in younger demographic groups, as symptoms can be frequent, persistent, and potentially impact educational and occupational performance.[11,12]

Digital eye strain, also known as computer vision syndrome, is a group of eye and visual symptoms associated with frequent and prolonged use of digital devices such as computers, tablets, and smartphones. These symptoms can include eye strain, headaches, blurred vision, dry and irritated eyes, and other discomforts experienced during and after prolonged screen use.[1,13–16] The growing reliance on digital devices highlights the need to understand and address the factors that contribute to digital eye strain. One important factor is accommodation latency, the difference between the actual focus of the eye and the optimal focus required for a viewing distance.[17–21] Prolonged screen time can cause accommodation fatigue, which can lead to symptoms of visual discomfort.[22,23] Proper accommodation and the pupillary light reflex are essential for clear and comfortable vision, and disruption of these processes is a key mechanism underlying digital eye strain.[24]

Accommodation, or the eye's ability to change focus to maintain sharp vision at varying distances, is important in the development of digital eye strain.[25] Prolonged close work, such as viewing a digital screen, requires prolonged accommodation, which can lead to accommodation fatigue and spasm.[26]. Accommodation latency plays an important role in the physiology of digital eye fatigue, particularly during prolonged near tasks such as screen use.[17,24,26,27]. This phenomenon occurs when the retinal conjugate point of the accommodating eye cannot reach a near object, causing visual discomfort and strain.[27,28]. Failure to accomodate to demand can exacerbate symptoms related to visual disturbances, which are often associated with adaptation errors and fatigue resulting from prolonged close work. In addition, accommodative fatigue, which is characterized by the decreasing ability of the eyes to focus accurately over time, can also contribute to further this stress.[13,15,16] As the eye struggles to maintain focus, individuals may experience blurred vision and eye strain, indicating adaptive dysfunction. Additionally, adaptation latency, which refers to 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.[15–17,29,30].In summary, the interplay between lag of accommodation, accommodation fatigue and dysfunction highlights the physiological challenges of prolonged digital engagement and the need for strategies to mitigate these effects. This can manifest as eye strain, headaches and visual impairment, highlighting the strong relationship between accommodation and digital eye strain.

Prior research on the effect of digital device use on accommodation response has yielded several notable findings. Studies indicate that prolonged close work, particularly with digital devices, can decrease accommodation dimensions and comfort, resulting in decreased placement efficiency.[18,19,31–33] In addition, evidence suggests that viewing distance and font size on digital displays may affect accommodation requirements and contribute to symptoms of digital eye strain.[34] Previous studies have also shown that higher screen resolution can reduce eye fatigue and improve visual comfort, possibly by reducing the strain on the adaptive system.[21,35,36] However, the effect of display color on adaptation remains unclear, as few studies have detected differences in adaptive responses to changing color temperature.[37,38] Additionally, shorter viewing distances are associated with increased demands for accommodation, potentially contributing to eye strain and fatigue.[39] Previous studies have been limited by factors such as lack of randomization, objective assessment, target age group, diagnostic criteria, and longitudinal data.

This study investigates how text size affects the accommodative responses of people with digital eye strain. Previous research has looked at the relationship between accommodation and digital device use, but more study is needed to improve visual ergonomics and reduce digital eye strain or computer vision syndrome. By exploring the effect of text size on the accommodative response in this group, the study provides valuable insights for developing practical solutions to address the growing problem of digital eye strain.

2. Methods

2.1 Participants And Ethical Approval

A total of 324 subjects were screened using the validated Computer Vision Syndrome Questionnaire[40], 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 an optometrist eye examination and met the following inclusion criteria: reported symptoms of digital eye strain, had emmetropia in each eye, had best corrected visual acuity of 0.00 logMAR or better in both eyes, had no systemic disease or drug treatment in the past 24 hours, had no history of refractive surgery, orthokeratology, strabismus, amblyopia, or binocular vision anomalies , and abstained from alcohol consumption in the past 24 hours and had at least 7 hours of sleep. The study protocol was approved by the Institutional Review Board((SEH/BLR/EC/2023/I02) in accordance with the principles of the Declaration of Helsinki. A convenient sampling method was used, and subjects who visited the hospital were included after providing informed consent.

Based on a pilot study of 10 subjects that found the standard deviation of the compliance response to be 0.30 D and aimed for a 95% confidence interval with a 5% margin of error, the required sample size was calculated to be 46 subjects. The sample size was calculated using the formula shown in Figure 1.

$$\text{Sample size} = \frac{2SD^2(Z_{\alpha/2}+Z_\beta)^2}{d^2}$$

SD – Standard deviation = From previous studies or pilot study
$Z_{\alpha/2} = Z_{0.05/2} = Z_{0.025} = 1.96$ (From Z table) at type 1 error of 5%
$Z_\beta = Z_{0.20} = 0.842$ (From Z table) at 80% power
d = effect size = difference between mean values

Fig. 1. A pilot study (n=10) estimated a standard deviation of 0.30 D. To achieve a 95% CI with a 5% margin of error, a sample size of 46 subjects is needed

2.2 Experimental Conditions

The study investigated adaptive response behavior and pupil dynamics while individuals read a 2-minute text passage on an LED screen 50 cm away[41]Screen brightness was kept at four hundred lux, as was room illumination, monitored using a certified lux meter (Sigma LX-1010B). The viewing distance of 50 cm was determined according to a previous study[41] found that this was a comfortable distance for digital display users. The experiment included three font size conditions: twelve-point, sixteen-point, and twenty-four-point, all in high-contrast black letters on a white background. Sheedy, Smith and Hayes recommended using the Verdana font[42] All measurements were made on the same 14-inch OLED panel with 2800x1800 resolution, 50 cm away from the participants' eyes. Following past research technique, the monitor was oriented at 105 degrees, resulting in a 15-degree viewing angle with participants' eyes slightly above the center of the screen. A WAM-5500 open-field autorefractometer was used under binocular conditions to continuously record pupil dynamics and accommodation 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[43]

2.3 Assessment Of Accommodative Response And Pupillary Dynamics

First, the WAM-5500 measured long-distance monocular refraction in static mode, which was then used to calculate the accommodation delay. Participants then read a two-minute text passage on a laptop using font sizes 12, 16, and 24 in random order. A 5-min break was allowed between each experimental condition to prevent acclimatization adaptation. Measurements of the dominant eye were recorded continuously.[44] Adaptation response data were analyzed to determine adaptation latency. The overall accommodative response to each stimulus is calculated by subtracting the break state away from baseline from the average accommodative reaction over the two-minute reading period. Data points with more than three standard deviations of variation, most likely due to eye blinking or registration errors, were eliminated in accordance with previous research recommendations.[37] Adaptation latency is calculated by subtracting the total adaptation response from the demand.

2.4 Procedure

During the first appointment, an optometrist examined all participants, completed the CVS-Q questionnaire, and had their binocular vision evaluated to ensure they met the inclusion criteria. On our second visit, we used the WAM-5500 automatic refractometer to measure elemental refraction at long distances. Participants were then given the opportunity to read the text fragment and familiarize themselves with the laptop. Participants were given the option to scroll through the text at their own pace and read it aloud. For the second visit, all participants attended at the same time, with a standard deviation of one hour. The open-field WAM-5500 autorefractometer was used to continuously assess pupil dynamics and accommodation response in High-Speed mode.

2.5 Statistical Analysis

Normality of data and equality of variances were determined using the Shapiro-Wilk test. A randomized experimental repeated measures design is applied. A repeated-measures ANOVA was used to compare accommodation response, accommodation latency, and pupil size across font sizes.

A post-hoc analysis with Bonferroni correction was also performed to examine the statistical significance of font size differences. All statistical analyses were performed using SPSS version 20; A p value of less than 0.05 indicates statistical significance.

3. Results

The results showed a statistically significant difference in the overall accommodative response among the three font sizes evaluated ($F = 4.25$, $p = 0.021$, $\eta 2p = 0.16$). As illustrated in Figure 2, the 12-point font size had the lowest mean accommodative response (1.84 ± 0.54 D) for a accommodation demand of 2.00 DS. Conversely, the accommodation response was highest for the 24-point font size, with a mean of 1.91 ± 0.54 D, followed by the 16-point font size (1.87 ± 0.55 D). Post-hoc analysis with Bonferroni correction showed that lag of accommodation for the 12-point font size was statistically significantly lower than for the 16- and 24-point font sizes with p=0.01.

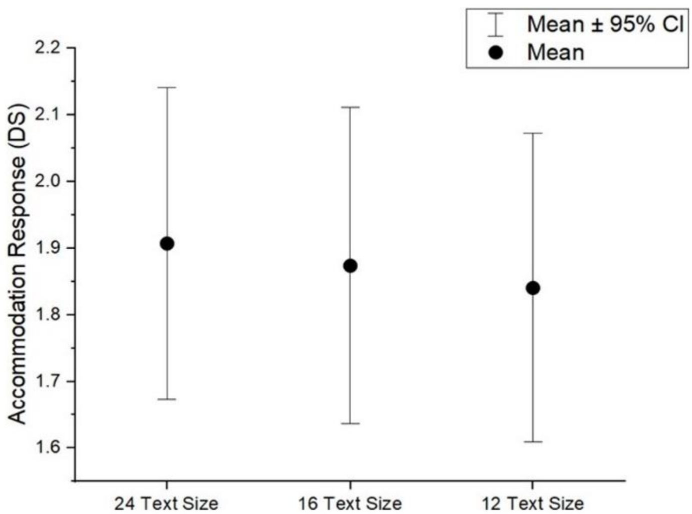

Fig. 2. As depicted in above figure 2, a positive correlation exists between font size and accommodation response. Larger font sizes elicit greater accommodation responses, indicating a more effective alignment of the eye's accommodative demand with visual stimuli. This suggests that larger fonts may contribute to reduced ocular strain by minimizing accommodative stress.

Table 1 provides a detailed summary of the adaptation response across the different text sizes, displaying the mean and standard deviation for each font size.

TABLE 1**.** ACCOMMODATION RESPONSE FOR VARIOUS TEXT SIZES

S.No.	Text Size (Points)	Accommodative response (Mean ± SD)
1	12	1.84 ± 0.54 DS
2	16	1.87 ± 0.55 DS
3	24	1.91 ± 0.54 DS

The study found a statistically significant difference in accommodation lag among the three font sizes ($F=10.56$, $p<.001$, $\eta 2p=0.32$). Accommodation lag was inversely related to text size. The 12-point font had the highest lag of 0.16 ± 0.54 D, followed by the 16-point font as 0.13 ± 0.55 D, and the 24-point font had the lowest lag of 0.09 ± 0.54 D, as shown in Figure 3. Post-hoc analysis revealed that the 12-point font size had significantly greater accommodation lag ($p=0.03$) compared to the 16- and 24-point font sizes.

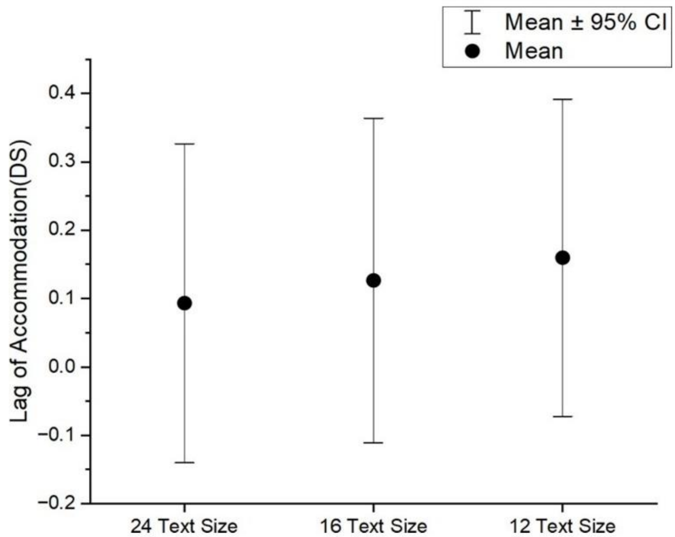

Fig. 3. Lag of accommodation for various text sizes. As illustrated in above figure 3, a negative correlation is observed between font size and accommodation lag. Smaller font sizes exhibit longer accommodation lags, suggesting a delayed or less efficient response of the eye's accommodative system. Conversely, larger font sizes demonstrate shorter accommodation lags, indicating a more rapid and precise alignment of the eye's accommodative demand with visual stimuli. This implies that larger fonts may contribute to reduced ocular strain by minimizing accommodative lag and associated discomfort.

Table 2 provides the detailed mean and standard deviation of accommodation lag for each font size.

TABLE 2 LAG OF ACCOMMODATION FOR VARIOUS TEXT SIZES

S.No.	Text Size (Points)	Lag of accommodation: (Mean ± SD)
1	12	0.16 ± 0.54 DS
2	16	0.13 ± 0.55 DS
3	24	0.09 ± 0.54 DS

The overall pupil response differed significantly among the three font sizes ($F = 28.06$, $p <.001$, $\eta 2p= 0.56$). As shown in Figure 4, the mean pupil size was 3.07 ± 0.34 mm for the 12-point font size, 3.17 ± 0.47 mm for the 16-point font size, and 3.29 ± 0.44 mm for the 24-point font size. Post-hoc analysis with Bonferroni correction ($p<.001$) revealed that pupil size for the 12-point font was significantly smaller than for the 16- and 24-point font sizes.

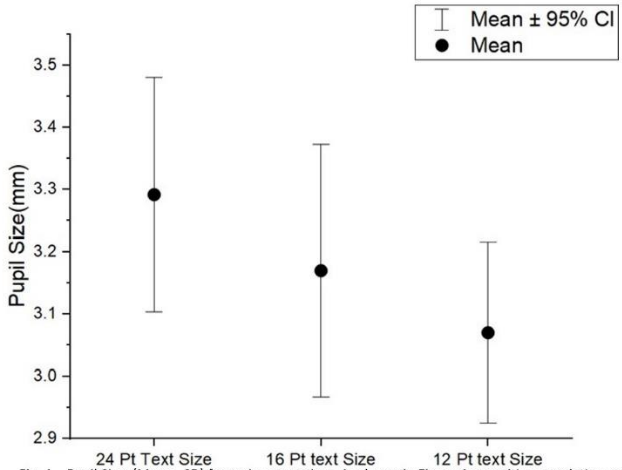

Fig. 4. Pupil Size :(Mean SD) for various text sizes. As shown in Figure 4, a positive correlation exists between font size and pupil size. Larger font sizes are associated with larger pupil diameters, suggesting a more relaxed state of the eye's pupil. Conversely, smaller font sizes exhibit smaller pupil diameters, indicating pupillary constriction. This constriction may be an attempt to improve visual acuity by increasing depth of field, but it can also contribute to accommodative stress and potential discomfort in the near triad system

Table 3 provides the detailed mean and standard deviation of pupil size for each font size.

Table 3 Pupil Size :(Mean ± Sd) For Various Text Sizes

S.No.	Text Size (Points)	Pupil Size :(Mean ± SD)
1	12	3.07 ± 0.34 mm
2	16	3.17 ± 0.47 mm
3	24	3.29 ± 0.44 mm

4. Discussion & Conclusion

The study findings indicate that font size has a significant impact on subjects' dynamic accommodation and pupil responses during digital reading tasks. Larger font sizes, such as 24-point, elicit stronger accommodative responses than smaller 12-point fonts. This suggests that using larger text on digital displays may increase the eyes' ability to focus, potentially reducing visual stress associated with prolonged close-up work. The apparent link between increased font size and greater accommodative response builds on and validates previous research, highlighting the importance of optimizing text size to improve visual comfort and user experience for digital device users.[45]

The study findings suggest that larger font sizes on digital displays are associated with reduced accommodation lag, which is a key factor in reducing digital eye strain. Specifically, the 12-point font exhibited the longest accommodation delay, while the 16-point and 24-point fonts showed progressively shorter lags. This suggests that larger text sizes enable better focusing ability, which may reduce digital eye strain symptoms caused by increased accommodation lag.[26]The improved accommodative response with larger font sizes indicates that the eyes can adapt and focus more easily when reading large text, thereby reducing visual strain and fatigue from prolonged digital device use, especially for those who are prone to digital eye strain. These results underscore the importance of font size as a key factor in optimizing visual comfort and user experience for digital display users. The link between increased font size and reduced accommodation gap is based on and validated by previous research, highlighting the important role of text size optimization in enhancing visual comfort and user experience for digital device users.[46,47]

The study findings reveal a direct relationship between text size on digital displays and pupil dynamics. Larger font sizes were associated with larger pupil sizes, while smaller font sizes were associated with smaller pupil sizes. This suggests that using smaller text on digital screens may lead to greater pupil constriction, potentially increasing visual strain and discomfort for users. The positive relationship between text size and pupil size aligns with the well-established theory that the pupil contracts in response to increased accommodation demand for smaller font sizes, helping to increase depth of focus, but also contributing to eye strain.[1] These results underscore the importance of employing larger font sizes on digital displays to optimize visual comfort and reduce the risk of digital eye strain for users. By improving readability and reducing visual cognitive load, larger font sizes can be a highly effective strategy to enhance the overall user experience and reduce the harmful effects of prolonged digital device use.[48,49]

Our results suggest that increasing font size on digital displays triggers a stronger accommodative response of the eyes, which may help reduce symptoms of digital eye strain that can result from prolonged use of such devices. Our study suggests that font sizes 16 and 24 points are particularly beneficial in eliciting better accommodative responses, as they allow for more accurate and effective accommodation, increasing visual comfort and reducing eye fatigue. Additionally, smaller font sizes are associated with smaller pupil sizes; overall, the use of larger font sizes may be an effective strategy for increasing visual comfort and reducing the risk of digital eye strain by improving the eyes' ability to focus and adapt to the viewing environment.

While our study provides valuable insight into the effect of font size on accommodation function, it is important to acknowledge several key limitations. First, the investigation was limited to examining only three specific font sizes. It can be speculated that exploring a wider range of font sizes, including common typefaces such as Arial and Times New Roman, may have significantly different effects on participants' accommodative response and pupillary dynamics. Future research should expand the scope of font sizes examined to determine whether alternative fonts elicit distinct visual responses compared to the current findings. Additionally, the 2-minute reading task used in this study may not be long enough to fully capture the long-term effects of font size on accommodation response. Increasing the duration of the reading task in future studies may provide valuable information about how font size affects visual fatigue and strain during prolonged use. In addition, this study was limited to emmetropic participants, but previous research has shown that individuals with different refractive errors, such as near-sightedness or farsightedness, may exhibit different accommodative responses and pupil dynamics. Performing similar experiments with a wider range of refractive groups may help clarify how font size interacts with these individual visual characteristics. Overall, although the current results provide important preliminary evidence for the effect of font size on visual function, further research is necessary to expand the scope and depth of this investigation. This will help to better understand the nuances and potential applications of using font size to optimize visual comfort and reduce the risk of digital eye strain among users of various digital display technologies.

In conclusion, this study provides strong evidence that increasing font size on digital displays can have a significant positive effect on visual function and comfort. The findings demonstrate that larger font sizes, such as 16-point and 24-point, are associated with shorter accommodation lag and large pupil sizes, which are important factors in reducing symptoms of digital eye strain. By improving the eyes' ability to focus and adapt to the viewing environment, the use of larger font sizes can effectively increase visual comfort and reduce fatigue during prolonged use of digital devices. These results underscore the importance of font size optimization as a practical strategy to enhance the overall user experience and reduce the harmful effects of digital eye strain. Further research investigating a wider range of font sizes and refractive groups will help expand our understanding of this relationship and guide the development of more visually comfortable digital display technologies.

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