Cognitive Demand, Concurrent Viewing Distances, and Digital Eye Strain

By

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Thesis

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Abstract

**Purpose:** Digital devices are now ubiquitous in modern daily life. Reports of digital eye strain (DES) symptoms are occurring frequently, particularly since the recent COVID-19 pandemic. Despite its prevalence, the mechanisms underlying DES have not been fully elucidated and there is currently no clinically proven treatment. Given that both mental effort and the accommodative and vergence demand have been associated with DES, the purpose of this study was to evaluate the relationship between the cognitive demand of the task, mode of presentation, working distance and symptoms of DES.

**Method:** The study was performed on 30 young, normally-sighted individuals. Each participant completed four trials, each of which included a 30-minute reading task. The four conditions entailed: (1) a cognitively demanding task performed on a digital device (tablet) and (2) a less cognitively demanding task performed on the same digital device. Trials (3) and (4) were identical to (1) and (2) except that the tasks were performed on printed paper. Both prior to and immediately following each 30-minute task, subjects completed a 10 question DES symptom survey. For all four conditions, subjects wore a Clouclip, a spectacle-mounted device which uses infrared technology to monitor the working distance objectively every 5 seconds.

**Results:** While all four 30-minute reading tasks induced symptoms of DES, the increase in symptoms was greater for the cognitively demanding tasks (p= <0.0001). However, there was no significant difference in symptoms between performing the tasks on paper
versus the tablet computer (p=0.83). With regard to working distance, there was no difference between the four testing conditions (p=0.11). However, all tasks showed a similar significant reduction in working distance (p=0.001), on average from 32 to 30cm, over the first ten minutes of the task, with the working distance remaining relatively stable after this initial period.

**Conclusion:** These results suggest that cognitive demand plays a greater role in DES than the mode of presentation. In addition, we found no evidence that working distance varies with cognitive demand or the method of presentation. However, it did decrease during the first 10 minutes of each trial. Further work is needed to explain the role of cognitive demand in DES.
Introduction

Definition of Digital Eye Strain

Digital Eye Strain (DES) is defined by the American Optometric Association (AOA) as “a group of eye and vision related problems that result from prolonged computer, tablet, e-reader and cellphone use”. This condition, also known as Computer Vision Syndrome (CVS), has been associated with a wide range of symptoms, with no definitive cause identified to date. Symptoms of DES can be broken down into two broader categories, described as extrinsic and intrinsic symptoms (Sheedy et al. 2003). Sheedy and colleagues classified extrinsic symptoms as those commonly described in dry eye disease (DED) such as burning, irritation, tearing and dryness of the anterior segment. These symptoms can be enhanced by holding the upper eyelid open during reading, thereby preventing rewetting of the ocular surface, or alternatively reading in upgaze, which exposes a greater portion of the corneal surface leading to enhanced evaporation of tears. In addition, viewing small fonts or excessive flicker has also been shown to induce extrinsic symptoms of DES, although the cause is not entirely clear. Intrinsic symptoms, by contrast, are those which can commonly be attributed to increased accommodative and vergence demand. This includes frontal headaches, generalized eyestrain and ache behind and around the eyes. In addition, intrinsic symptoms also include those from accommodative or vergence dysfunction, such as blurred or double vision at near, blurred distance vision following a near task or an inability to refocus the eyes when changing viewing distance. It then follows that DES is strongly correlated
with DED, since many of the symptoms are shared between the two conditions. For example, office workers reported significant symptoms (Portello et al. 2012) based on the Ocular Surface Disease Index (OSDI) questionnaire (Schiffman et al. 2000), while more than four hours of screen time in office workers has also been associated with an increased risk of DED (Uchino et al. 2008).

*Prevalence of DES and Quality of Life*

For more than 20 years, digital screens have become ubiquitous in daily life. According to the Vision Council, in 2016 over 90% of adults used devices at least two hours per day (The Vision Council, 2016). However, by 2020 the use of digital devices had skyrocketed as a result of the COVID-19 pandemic, with many offices and schools going entirely remote, forcing staff and students to work and learn on digital devices for upwards of 8 hours per day. A 2020 report described an average increase in screen use during the COVID-19 lockdown of over 4 hours per day among participants, which included individuals older than 18 years of age who were students, workers or homemakers, with total screen use often exceeding 8 hours per day (Bahkir et al. 2020) It is no surprise then that the prevalence of DES has risen significantly during the COVID-19 pandemic. While the prevalence of DES is difficult to determine, given the lack of a standard definition, prevalence reports have exceeded 50%, with some as high as 78% during the COVID lockdown (Ganne et al. 2021, Alabdulkader 2021). Although the symptoms of DES are transient, sufferers of DES may also report an overall reduction in their quality of life (Hayes et al. 2007).
Treating Symptoms of DES

Despite epidemic levels of DES, no current recommendations have been shown to ameliorate symptoms adequately. Some have concluded that ergonomic adjustment to the working environment, such as increased working distance, viewing screens in downgaze and reducing glare from surrounding lights is the most effective way to combat DES. In addition, combatting symptoms of DED with lubricating drops can also provide relief from dry eye related DES symptoms (Loh and Redd 2008).

Digital Eye Strain versus Eyestrain

While eyestrain is a common visual complaint, there is evidence to demonstrate that the discomfort arising from digital screens induces worse symptoms than printed text (reviewed in Blehm et al. 2005 and Chu et al. 2011) leading to the acknowledgement of DES as a separate entity. However, the mechanism behind this is not yet fully understood. As will be addressed in the next few sections, various theories of DES have attempted to elucidate why screens appear to induce a distinct form of strain. One such theory is that screens emit blue light, whereas paper texts do not. Another proposal is that smaller screens, such as iPhones, may be held at closer viewing distances than paper (Lan et al. 2018, Golebiowski et al. 2020), thereby producing higher vergence and accommodative demands. Finally, as will be addressed, near tasks on screens alter both blink rates and the proportion of complete blinks (Portello et al. 2013, Chu et al. 2014, Golebiowski 2020), leading to symptoms of DED and DES. However, none of these theories currently have
sufficient evidence to explain the phenomenon of DES as compared to non-digital eye strain.

Various studies (reviewed in Blehm et al. 2005 and Rosenfield 2011) have reported that symptoms of eyestrain are worse when comparing the same reading or near task performed on paper versus a digital screen. One such investigation showed significantly greater symptoms following a 20-minute reading task performed at a set working distance of 50cm from a desktop computer screen compared with the same task viewed on paper (Chu et al. 2011). However, closer analysis of these results demonstrated that of the ten symptoms listed in the questionnaire, only “blurred vision while viewing the text” showed a statistically significant difference. A further investigation compared a similar reading task on paper versus using an Amazon Kindle or an Apple iPad tablet computer. While reading on the Kindle, symptoms for tired eyes and eye discomfort were significantly higher than when reading from paper, but the overall mean symptom score was not significantly different. In addition, the authors observed no significant difference in reading rate between paper and the Kindle. However, when the scores for paper versus the iPad were compared, no significant difference in symptom score was found, although they did record a decrease in reading rate and an increased lag of accommodation (Hue et al. 2014). These studies demonstrate that the mode of presentation may generate differences in DES symptoms, although it is not fully clear why or which symptoms are impacted consistently. Further, Hue et al. demonstrated that not all screens produce the
same symptoms. This has led to various theories behind the causes of DES, which will be addressed in the following sections.

Blue Light and Digital Eye Strain

In recent years, blue light emitted from screens has been suggested as a possible cause for DES. Many commercial companies have marketed both prescription and non-prescription blue light filters directly to consumers, in the form of screen overlays and lenses, despite a lack of clear evidence to demonstrate that blue light is indeed the cause of DES. One investigation attempted to demonstrate that the use of blue light filters improved symptoms of DES, using critical flicker fusion frequency (CFF) as an objective measure of eye strain (Lin et al. 2017). However, more recent data has shown that a reduction in CFF is not a reliable way of assessing DES, since it shows no correlation with the severity of subjective symptoms (Yan and Rosenfield, 2022, Anderson et al. 2022). Indeed, multiple randomized controlled trials found no significant difference in symptoms of DES when viewing though blue blocking lenses compared with control lenses (Singh et al. 2021, Rosenfield et al. 2020). Other research has demonstrated that blue blocking lenses are no more effective than a neutral density filter, which may also reduce the overall brightness and glare of the screen (Palavets and Rosenfield, 2019).

Therefore, although blue light has received extensive media and marketing attention and the sale of blue-blocking lenses generates millions of dollars annually, there is little to no evidence to support the proposal that blue light contributes to symptoms of DES.
Accommodation and Vergence in Digital Eye Strain

To the contrary, there is good evidence to suggest that accommodative and vergence demands can induce symptoms of DES (reviewed in Kaur et al. 2022). The most logical support for this theory is that many intrinsic symptoms of DES are identical to those of clinical accommodative or vergence dysfunction. This suggests a strong interplay between sustained accommodation and vergence and the development of symptoms. One study evaluated the relationship between hours spent on digital devices during the COVID-19 pandemic in school-aged children and symptoms using the Convergence Insufficiency Symptom Survey (CISS) (Borsting et al. 1999) as well as clinical measures of heterophoria and accommodative amplitude (Mohan et al. 2021). They found that spending four hours or more per day on a digital device was a significant risk factor for increased symptoms. In addition, they observed that the group of children who spent more than four hours per day on the computer had higher rates of abnormal convergence, defined as greater than 6 Δ exophoria at near. In addition, BI prism has been shown to reduce CISS symptoms in adults with convergence insufficiency (Navobati et al. 2020), which might provide a viable treatment option to reduce discomfort. Further, they found greater accommodative amplitudes in the group that spent more than four hours per day on digital devices. In contrast, other studies have reported a decreased amplitude of accommodation following digital device use in early presbyopes (Kwon et al. 2016). Taken together, there is clear support for the theory that accommodative and vergence dysfunction plays a role in DES.
Further, there is evidence to support the notion that increased accommodative and vergence demands can impact symptoms of DES. During the course of a 60-minute reading task from an Apple iPhone, test subjects significantly reduced their working distances from an average working distance of 29.2 cm over the duration of the task to 27.8 cm during the last ten minutes of the task (Long et al. 2017). By reducing their working distance, the accommodative and vergence demands will increase. In the same investigation, the levels of DES increased as working distance decreased, suggesting a strong connection between working distance, and thereby accommodative and vergence demand, and symptoms of eye strain. However, this study had various limitations. First, working distance was measured using photographs taken at 1-minute intervals and was not monitored continuously. In addition, the average working distance was calculated over a 10-minute period, which may ignore more subtle changes over time. Further, the close working distances adopted for iPhones (Bababekova et al. 2011; Lan et al. 2018), which were markedly shorter than those previously reported for other digital devices such as desktop or laptop computers, may be because iPhones are smaller and handheld and may not be comparable with printed materials. Nevertheless, there is evidence that increased accommodative and vergence demand can induce symptoms of DES.

*Blinks, Dry Eye, and Digital Eye Strain*

Another common theory regarding DES is that digital devices impact blink rate, thereby inducing symptoms of DED and DES. Cognitively demanding sustained near tasks, performed either on paper or on electronic screens, have been shown to reduce the
number of blinks per minute (Abushara et al. 2017). Importantly, Chu et al. (2014) demonstrated no significant difference in blink rate between digital and hardcopy presentations when subjects performed identical tasks. However, the number of incomplete blinks is higher with screen use than when reading from paper (Chu et al. 2014). Incomplete blinks are defined as when the upper eyelid fails to cover the entire corneal surface. During incomplete blinks, the inferior cornea is not moistened with tears, which can result in symptoms of burning and lead to tearing. Further, fewer blinks coupled with greater incomplete blinks leave the ocular surface exposed to the air, resulting in dry eye. As described above, symptoms of DED are similar to extrinsic symptoms of DES in that burning and tearing are common to both conditions. In a similar vein, habitual contact lens wearers are also more likely to suffer from DES (Tauste et al. 2016), probably due to the interplay between contact lens induced dryness and the onset of DES symptoms.

**Cognitive Demand and Eye Strain**

Cognitive demand or load, described as the mental difficulty of a task, has also been associated with symptoms of DES, (Gowrisankaran et al. 2012) although the mechanism linking the two has not been fully elucidated. One possible connection may be the near triad, comprising pupillary constriction, convergence and accommodation, which is under the control of the autonomic nervous system. The ciliary muscle, which is responsible for accommodation, receives dual innervation from the parasympathetic and sympathetic divisions of the autonomic nervous system (reviewed by Gilmartin, 1986).
Increased cognitive demand of a reading task has been shown to increase tonic accommodation when compared with a less demanding near task. This supports the notion that there is strong interplay between the parasympathetic and sympathetic systems and their control over the accommodative response (Bullimore and Gilmartin, 1987). It therefore follows that the near triad will be impacted by autonomic tone. In fact, pupil size has been shown to increase during a short-term, cognitively demanding task, namely the Stroop test (Mihelcic and Podelsek, 2022) potentially due to increased sympathetic output under physiologically stressful conditions. The Stroop Test is a psychological assessment in which non-congruous stimuli are presented to a subject, in the form of the names of colors printed in various ink colors that do not match that of the printed word. The subject is then asked to either read the words, ignoring the color in which the word is printed, or conversely to name the color of the ink, while ignoring the printed word (Stroop 1935). This test is widely used in psychology to assess cognitive interference and is considered a cognitively challenging task (reviewed by Scargina and Tagini 2017). In addition, there is a relationship between fluctuations in accommodation and the level of cognitive engagement in a task, whereby tasks that require active engagement result in less variability in the accommodative response when compared with passive, non-reading, tasks (Roberts et al. 2018). Gowrisankaran et al. (2012) evaluated the interplay between eyestrain, visual strain and cognitive load. The authors observed that visual strain, such as induced refractive blur, reduced contrast, lowered visual quality and increased cognitive demand, thereby inducing statistically significant symptoms of
DES. Further, the higher the cognitive load, the greater the amount of induced DES, even under the same visual conditions. Together, these data implicate a role for cognitive load in DES, although the mechanism is not yet fully understood.

Goals of this Study

In this study, we aimed to evaluate the interplay between the mode of presentation, level of cognitive demand, working distance and symptoms of DES. We established two levels of cognitive demand: a low cognitive demand task of reading a 7th grade children’s novel, and a high cognitive demand task of reading random words from adult novels and identifying every word beginning with a letter specified by the examiner. In addition, each of these tasks were performed twice, once on paper and once on an iPad tablet computer. Whereas prior studies (Long et al. 2017) utilized an iPhone which is smaller than most printed texts, we used an iPad placed on a clipboard so that the size of materials held by the subject was the same for both the digital and printed materials. In addition, the clipboard ensured that the weight of the system was similar for the two viewing conditions and would not impact viewing distance significantly. Further, working distance was measured objectively using a Clouclip (www.clouclip.com). This device comprises an infrared sensor placed on the subject’s spectacle frame, and measures the working distance objectively every 5 seconds. The accuracy of the Clouclip has been verified and the device has been shown to be accurate over a range of 5-120cm with 2cm of error (Bhandary and Ostrin 2020). Indeed, for an assumed working distance of 30cm, the device has an approximate 2% maximum relative error (Wen et al. 2021). This
allowed us to take frequent, objective measurements of working distance, and obtain an average working distance with greater accuracy. We hypothesize that there is a strong correlation between cognitive demand and working distance, whereby subjects would instinctively decrease their working distance (i.e., move the target closer) when concentrating on a more cognitively demanding near task. This change will correlate with increased symptoms of DES. We anticipated that cognitive demand and viewing distance will play a greater role in DES symptoms than the mode of presentation alone.
Methods

Thirty subjects between the ages of 18 and 30 were recruited for participation from the SUNY College of Optometry. The mean age was 24.0 with a SD of 1.59 years and a range of 22-29 years of age; the study included 4 males and 26 females. Inclusion criteria required that subjects had distance and near visual acuity (VA) of log MAR 0.0 or better in each eye and binocularly. Exclusion criteria included a history of refractive surgery, diagnosis of ocular pathology, strabismus and accommodative or vergence dysfunction. Subjects were required to have normal binocular vision, which was defined as a distance heterophoria between $6\Delta$ exophoria (XP) and $6\Delta$ esophoria (EP), distance base-out (BO) vergence range blur of at least $5\Delta$, distance base-in (BI) vergence range blur greater than $4\Delta$, near heterophoria between $8\Delta$XP and $6\Delta$EP, near BO vergence ranges greater than $12\Delta$, near BI vergence blur greater than $9\Delta$, positive relative accommodation (PRA) $\leq -1.50D$ and negative relative accommodation (NRA) $\geq +1.25D$. For subjects who did not experience blur during the vergence range measurements, minimum break values were accepted in place of blur. Values were either taken from their last eye examination at the University Eye Center or were measured by ES. Subjects with spectacle or contact lens corrections were included and permitted to wear their habitual near refractive correction. However, they were instructed to use the same correction for all four trials. Subjects self-reported their heights for inclusion in analysis. All subjects provided written consent following a full explanation of the experimental procedures prior to their participation. The experimental protocol was in accordance with the
Declaration of Helsinki and was approved by the Institutional Review Board at the SUNY College of Optometry.

Subjects were required to perform four 30-minute reading tasks. Each task was performed at least 24 hours apart with no more than one week between sessions. These four tasks were: (A) reading random words from an Apple iPad tablet computer (Model number MD529LL/A, apple.com) which had a screen size measuring 20.3cm x 13.5cm, and identifying those words beginning with a letter specified by the experimenter. The reading material comprised paragraphs of unrelated words produced by copying the first and last word of each line from several adult-level fiction novels. This is a cognitively demanding task which has been previously shown in our laboratory to induce significant eye strain. (B) Reading Alice’s Adventures in Wonderland, by Lewis Carroll, a 7th grade level book on the same Apple iPad tablet. We hypothesized this task to be less cognitively demanding as all subjects are enrolled in an advanced graduate program. Tasks (C) and (D) were identical to (A) and (B) except that the tasks were performed on printed paper instead of an iPad. The text size on the iPad was carefully matched to the size of the printed text, and subjects were instructed not to change the font or text size. For tasks (A) and (C), font size was 12-point Times New Roman font, and black on white with maximum contrast. For tasks (B) and (D), font size was approximately 16-point font with maximum contrast. For printed paper tasks, black ink was printed on clean, 8.5 x 11 inch white paper. For digital tasks, maximum brightness was used on the iPad, and subjects were instructed not to adjust the brightness for the duration of the task. In
addition, for all tasks, subjects were seated in the same laboratory position, utilizing the room illumination and an overhead lamp directed at the reading material.

Immediately prior to and after each reading task, subjects completed a symptom questionnaire devised by Hayes et al. (2007), in order to quantify ocular and visual changes that were induced by the reading task. This questionnaire, shown in Figure 1 below, has been used previously in our laboratory and has shown to be repeatable (Rosenfield et al. 2012). Subjects then completed the same questionnaire immediately following the 30-minute reading task.

Figure 1: Survey of DES symptoms adapted from Hayes et. Al 2007.

For all conditions, subjects were given the reading material (iPad or paper) on a clipboard so that the overall size and weight of the material would be as similar as possible. Subjects were instructed to hold the reading material at a viewing distance they found comfortable, with the stipulation that the clipboard must be held upright and that
their chin should point towards the reading material. This was done to ensure that the measurements of working distance would be accurate.

Reading distance was assessed objectively using a Clouclip device. This is a continuously measuring objective rangefinder that has recently been validated (Bhandary and Ostrin 2020, Wen et al. 2021). It was attached to the temple of a spectacle frame via a rubber sleeve as shown below in figure 2.

![Figure 2: Clouclip device attached to the right temple of spectacle frames A. front view B. Side view](image)

For subjects who habitually wore spectacles, the device was attached to the right temple of their own spectacle frame. For subjects who were either habitually uncorrected or wore contact lenses, the device was attached to the right temple of an empty spectacle frame with no lenses in place. The Clouclip emits an infra-red beam every 5 seconds to assess the viewing distance, and data were uploaded to an Excel spreadsheet (www.microsoft.com) for analysis. The device has good repeatability and 95% limits of agreement of ± 2.00cm for measurements between 5 and 120cm (Bhandary and Ostrin 2020). However, more recent research utilizing the Clouclip device has identified errors in measurement for working distances between 5 and 9cm and greater than 99cm (Doron
et al. 2023). In the latter case, the subject was looking at a distance target, but the Clouclip device still registered a measurement for a near target. Therefore, for the purposes of this experiment, only values greater than 10cm and less than 100cm were considered valid measurements of the near task, and data points outside of this range were excluded.

**Statistical analysis**

The characteristics of the participants were first examined by descriptive statistics, including mean ± standard deviation (SD) for continuous variables or percentages (counts) for categorical variables. For the continuous outcomes, we used the Shapiro-Wilk test to confirm the normality of measurements prior to performing statistical analyses. All statistical tests were two-sided, and a value of $P < 0.05$ was considered statistically significant.

Symptom scores before (pre-task) and after (post-task) were each analyzed using a repeated measures analysis of variance (ANOVA) with two within-subjects factors of time and type of tasks (A, B, C and D). When significant main effects or interactions were found ($p < 0.05$), post hoc tests with Bonferroni correction were then conducted. The differences of tasks on symptom scores were assessed using Bonferroni adjusted paired Wilcoxon Rank Sum tests on the difference in measurements from pre-task to post-task. The Wilcoxon rank sum test (Kruskal-Wallis) where normality was violated the
mixed effect linear regression was used to examine the longitudinal trend adjusting for other relevant covariates in evaluating the significant changes.

We analyzed the working distances over the 30-minute task using linear regression with two factor analysis for condition and time. Finally, we used linear regression to establish if there was a significant correlation between the height of the test subject and their working distance. Our goal was to determine if the mode of presentation (i.e., paper versus iPad) or cognitive demand of the task played a greater role in inducing symptoms of DES. We hypothesized that the iPad condition would induce greater symptoms of DES than the same task performed on paper. In addition, we anticipated that more cognitively demanding tasks would induce greater symptoms of DES than a less cognitively demanding task performed on the same media.

Results

Thirty subjects (4 male, 26 female) completed the study, performing each of the four 30-minute reading tasks. The average age of subjects was 24 years (max=29, min=22, SD=1.6). Data from all 30 subjects were included for analysis.

The average symptom score before and after each task is displayed in figure 3. The mean increase in symptoms scores after each task is displayed in figure 4.
Figure 3: Box and whisker plot of symptoms before and after reading tasks. Task A is high cognitive demand from iPad. Task B is low cognitive demand from iPad. Task C is high cognitive demand from paper. Task D is low cognitive demand from paper. Numbers represent mean symptom score out of 100.

Figure 4: Mean Increase in symptoms after reading tasks. Task A high cognitive demand from iPad. Task B is low cognitive demand from iPad. Task C is high cognitive demand from paper. Task D is low cognitive demand from paper. Numbers represent mean increase in symptom score following the 30-minute reading task.
As shown above (Figure 3) all groups had significant outliers which caused the data set to deviate from normality, however all subject data was included in the final analysis and no outliers were excluded. In addition, since sphericity was violated, the Greenhouse-Geisser sphericity correction was applied to the data before repeating the two-way ANOVA test as shown below in Table 1.

<table>
<thead>
<tr>
<th>Effect</th>
<th>F</th>
<th>P value</th>
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<tbody>
<tr>
<td>time</td>
<td>41.450</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Task*</td>
<td>3.247</td>
<td>&lt;0.026</td>
</tr>
<tr>
<td>Time: task</td>
<td>9.488</td>
<td>&lt;0.0001</td>
</tr>
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</table>

With this correction, a statistically significant change was attributed to both time and to task, whereby all tasks had a significant increase in mean symptom score and that there were significant differences between the four task conditions. Of note, the interaction between time and task was statistically significant, in that depending on the type of task, pre- versus post-task symptom scores were statistically different. The paired Wilcoxon rank sum test adjusted for multiple comparisons was then performed to confirm that each task had a statistically significant increase in mean symptom score as shown below in Table 2.

<table>
<thead>
<tr>
<th>Task</th>
<th>Pre</th>
<th>Post</th>
<th>p-value adjusted *</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>6.36 (6.26)</td>
<td>20.56 (16.62)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>B</td>
<td>7.63 (10.68)</td>
<td>15.60 (15.22)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C</td>
<td>6.00 (6.62)</td>
<td>18.20 (14.05)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>D</td>
<td>6.06 (6.55)</td>
<td>11.03 (9.43)</td>
<td>0.001</td>
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</table>

Utilizing a paired Wilcoxon test adjusted for multiple comparisons.

Finally, as displayed in Table 3, pair-wise tasks for the Wilcoxon rank sum test demonstrated that there were no statistical differences between the pre-task surveys of
any two tasks. This means that prior to all tasks, our subjects had similar levels of eye strain. However, there was a significant difference in the post-task symptoms when comparing tasks A and B, A and D, C and D. Task A was a cognitively demanding task performed on iPad, while task B was a non-cognitively demanding task performed on iPad. Task A showed a significantly greater increase in symptoms as compared to task B. Similarly, task A showed a significantly greater increase in symptoms as compared to task D, a non-cognitively demanding task performed on paper. Further, when comparing tasks C and D, a cognitively demanding and non-cognitively demanding task, respectively, performed from paper, task C had a statistically significant greater increase in symptoms post-task. Of note, there were no differences found between the post-task symptoms of tasks A and C, cognitively demanding tasks performed from iPad and paper, respectively, or between B and D, non-cognitively demanding tasks performed on iPad and paper, respectively.

<table>
<thead>
<tr>
<th>Table 3: comparison between pair-wise tasks by Wilcoxon rank sum test</th>
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<tr>
<td>time</td>
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<tr>
<td>Pre</td>
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<td>Pre</td>
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Working distances over the course of the 30-minute tasks were analyzed to determine if the mode of presentation (i.e., paper versus iPad) was associated with a change in working distance. Using two factor ANOVA for testing condition and time, time was significant \( (F = 2.77; \text{df} = 6.812, \ p = 0.01) \) while condition was not significant \( (F = 2.02, \text{df} = 3, \ 812; \ p = 0.11) \). Therefore, average working distance for all four testing conditions were compiled and are displayed below in Figure 5.

![Working Distance (cm) vs Time (min) for All Conditions](image)

*Figure 5: Working distance (cm) vs time (min) for all testing conditions. Average initial working distance is 32 cm. Average final working distance at 30 minutes is 29 cm. Error bars indicate +/- 1 SEM.*

The most significant reduction in working distance took place during the first ten minutes of trial. Therefore, we analyzed the working distance for each subject over the initial ten minutes, broken down into two-minute increments, as shown below in Figure
6. For each of the four conditions, there was a statistically significant decrease in working distance (p=0.048, p=0.04, p=0.02, p=0.00003) for tasks A, B, C and D respectively.

![Graphs A: Working Distance (cm) vs Time (min) for Task A](image1)

![Graphs B: Working Distance (cm) vs Time (min) for Task B](image2)

![Graphs C: Working Distance (cm) vs Time (min) for Task C](image3)

![Graphs D: Working Distance (cm) vs Time (min) for Task D](image4)

Figure 6: Working distances (cm) vs time (minutes) over the first ten minutes of each of the four tasks, A, B, C and D respectively. Each show a statistically significant decrease in working distance using linear regression analysis over the first ten minutes.

We then evaluated whether working distance was correlated with self-reported subject height (see Figure 7). Using linear regression analysis, we found no significant correlation between height and working distance for the first two minutes ($r^2 = 0.002$, $p = 0.78$) of the reading task, nor during minutes 8-10 ($r^2 = 0.05$, $p = 0.26$) task. These two time periods were chosen due to the statistically significant reduction in working distance observed during the initial two minutes of the task and the subsequent stabilization of working distance from 10 minutes of the task and onward.
Discussion

Summary of Results

As described above, the results of this study analyzed three main areas. First, comparing symptoms of DES following four different near reading tasks, stratified by mode of presentation (iPad versus paper) and cognitive demand (i.e., 7th grade story versus adult level random words) with the goal of determining the contributing factors for symptoms of eye strain. Thirty-minute reading tasks at both high and low cognitive demands induced significant symptoms of DES. However, high cognitive demand tasks induced significantly more symptoms as compared to low cognitive demand tasks. Further, when comparing the same tasks performed on the iPad versus paper, there was no statistically significant difference in the symptoms induced, suggesting that the
cognitive demand of the task plays a greater role in inducing symptoms than the mode of presentation. Given that there does not appear to be a statistically significant increase in symptoms when viewing a digital screen as compared to performing the same task from paper, we question whether our subjects experienced DES or simple asthenopia from performing a sustained reading task for 30 minutes.

Next, the working distance during the 30 minutes of the near task was analyzed to determine whether there was a relationship between tasks that induce more symptoms of DES and working distance. We hypothesized that more cognitively demanding tasks would lead subjects to hold the material at a shorter working distance to aid in concentration. This thereby increases the accommodative and vergence demands of the task, resulting in greater symptoms of DES. This result would bolster the theory that DES is driven in part by increased demand on the accommodative and vergence systems, rather than the digital device alone. However, analysis revealed no significant differences between the four tasks with regard to working distance. All four conditions had similar working distances, and a similar significant decrease in working distance over the first ten minutes of the task. Despite these similarities in working distance, all four tasks did elicit statistically significant differences in DES symptoms as measured by the symptom survey. This indicates that the increase in symptoms seen with the more cognitively demanding tasks was not directly related to working distance.

Lastly, the heights of the test subjects were compared to their working distance during the first 10 minutes of the near task to determine if working distance is primarily
driven by the physical characteristics of the subject rather than the near task. No statistically significant correlation was found between height and working distance at early or later time periods within the first ten minutes of the near task.

**DES or Asthenopia?**

In this study, the mode of presentation did not appear to play a role in symptoms of DES, leading to the obvious question of whether DES (or CVS) is a unique and separate entity from nearwork-induced asthenopia. In the 1970s and 80s, when “visual display terminals” or older versions of computers first emerged for office workers, there was much concern regarding their safety and impact on vision. Of note, the displays were highly pixelated and difficult to read, inducing symptoms of glare and eyestrain (reviewed by Blehm et al. 2005). In a similar vein, it was noted that reading small print from lower resolution screens reduced readability (Miyao et al. 1989). However, in the present investigation, the digital device utilized was a modern Apple iPad. It appears that with the dramatic improvements in modern screens, whereby brightness can be readily controlled, contrast can be enhanced and resolution has improved dramatically, the digital device itself does not induce more symptoms inherently by its digital nature. Rather, in the earlier studies, pixilation, poor resolution, reduced contrast and flicker could have been the underlying cause of the observed differences when comparing reading tasks on computer screen versus paper. However, today, viewing a digital screen appears nearly identical to a printed copy of the same material.
Working Distance and Changes Over Time

As noted above, although there was no significant difference in working distance between the four testing conditions, a reduction in working distance was observed over the first ten minutes of the reading task. Reducing the average working distance from 32 cm to 30 cm increases the accommodative demand of the task from 3.125D to 3.333D. This change is not considered clinically significant as it is less than a quarter of a diopter, normally the smallest change in refractive examinations. With regard to vergence demand, that change would only alter the vergence demand of the task from approximately 19 to 20 prism diopters (Δ), which appears negligible. Therefore, it seems that the changes in working distance do not contribute to symptoms of DES, given that there was no significant difference between tasks and that the increase in demand was not clinically significant. Of note, this phenomenon of reduced working distance during the early minutes of a near reading task has been reported previously in Chinese myopic children (Bao et al. 2015). For a near reading task of 180 seconds, working distance reduced from 31cm to 25cm. In the same investigation, working distance was also significantly reduced for a near writing task, but not for a video game, where the initial working distance was shorter but did not change significantly during the duration of the task. This would suggest that working distance, and changes in working distance over time, are task specific. For the purposes of this investigation, two reading tasks of different cognitive demands were used. However, had we chosen two different tasks, such as a cognitively demanding reading task, and a non-cognitively demanding task such as
watching television from the same screen, then it is plausible that we might have observed differences in the initial and final working distances based on the nature of the task itself, and not on the basis of cognitive demand. It is therefore important to note that both tasks compared in the present study were involved reading, albeit at different levels of difficulty.

It is also important to note that the average working distance in this investigation was markedly shorter than 40 cm, and closer to 30 cm. This finding has significant clinical ramifications for testing and prescribing. First, it calls to question why the majority of near clinical testing is done at a standard 40 cm, when the average person may not be performing near tasks at that distance. In fact, patients complaining of asthenopia may demonstrate results within the normal ranges for heterophoria, vergence ranges, and NRA/PRA at 40cm, but may struggle to perform tasks at 30cm if that is their preferred working distance. Further, we observed a marked reduction in working distance over the first ten minutes of a sustained reading task. This means that when patients are asked to report their habitual working distance during the case history, they may be overestimating their distance by reporting their starting working distance, rather than their sustained working distance. Second, when prescribing near lenses for presbyopic patients without eye disease, the age expected near addition is typically capped at +2.50, assuming a 40cm working distance. However, perhaps an addition of +3.25 or +3.50D would be more appropriate for older patients with shorter working distances, especially given that closer working distance allows for relative distance magnification, thereby
making the print larger and therefore easier to view. Alternatively, the lower prescribed addition lenses may force absolute presbyopes to hold the device at longer distances, which might make the small font size difficult to resolve. Additionally, in clinical research settings, studies will often evaluate working distances for short tasks of 10 minutes (see Doron et al. 2023). However, since working distance decreases during that time period, it would be prudent to have slightly longer task durations of at least 20 minutes; perhaps allowing for 10 minutes of sustained reading after an initial ten minutes adaptation period, during which time the working distance may change.

**Height and Working Distance**

Since working distance did not correlate with the severity of DES symptoms, we hypothesized that working distance would relate directly to the physical height of the subject, which is presumably related to arm length and therefore comfort holding text. However, we found no significant correlation between working distance and body height. This was surprising given that the “Harmon working distance” (Harmon 1958) is frequently cited as an ideal viewing condition for visual comfort, especially in school-aged children. Harmon described the ideal viewing distance to be directly related to the length of the arm from the closed fist placed under the chin to the tip of the elbow and argued that the viewing distance should not be shorter than that. The obvious implication is that viewing distance in children should naturally be changing each year as the child grows as part of the development of the visual system. It would then follow that in adults, a comfortable viewing distance would also be related to arm length. However,
this phenomenon was not observed, possibly due to a narrow range of subject heights and limited range of working distances. A similar investigation (Doron et al. 2023) measured the Harmon distances of adult males. They showed that for male subjects with an average height of 176.7cm, the average Harmon distance was 38.4cm. However, our sample was predominately female, and the average height of subjects was 166.2cm. While we did not measure the Harmon distance on our subjects, we would presume that arm length would correlate with height, and therefore the average Harmon distance would be shorter.

Interestingly, given the average Harmon distance of 38.4cm for males cited above, then we would expect the corresponding distance for females to be shorter than that number, and the working distance findings observed here are consistent with that notion. That further brings into question the use of a standard clinical test distance of 40cm.

An investigation using myopic Chinese school children (Bao et al. 2015) showed a steady increase in working distance for a near reading task correlated with grade level, from 25cm in 1st and 2nd grade children to 28cm in 5th and 6th grade children. A similar study (Rosenfield et al. 2001) found a statistically significant correlation between reading distance and age in New York City children. These findings indicate that as children grow (and therefore increase their Harmon distance), then they concurrently increase their working distance. This finding also calls into question the reason behind clinical testing at 40cm, since it appears to be derived from Harmon working distance of the adult male of average height, rather than the universal truth. Indeed, it seems likely that body height,
and therefore the Harmon distance will also vary significantly with ethnicity, age and sex, further questioning the use of a single near viewing distance.

**Strengths**

In this study, we had each subject perform four reading tasks for 30 minutes per trial. While this duration may not seem excessively long, 30 minutes of continuous reading with no allowances for breaks provided highly demanding. In addition, all of the 30-minute tasks induced significant amounts of DES, confirming that the duration was sufficiently long to induce symptoms. Further, the working distance remained relatively stable after the first ten minutes of the task, allowing for the subject to perform the task for a further 20 minutes at a consistent distance. In addition, by utilizing the same cohort to perform all of the tasks, we were able to discern whether the mode of presentation or cognitive demand played a larger role in symptoms of DES. Further, we utilized objective, continuous measurements using the Clouclip device, which has more recently become available and has been verified for research use.

**Weaknesses**

However, it is important to stress that this study still relied primarily on subjective reports of symptoms based on a survey. This presents various limitations. First, although we chose a previously validated survey, there are a number of surveys for DES, and had we selected a different survey, then we may have obtained different findings. Additionally, subjects had no objective baseline on which to base their symptoms, and
some may be more accustomed to symptoms of eyestrain based on personal study habits, whereas others may have over-rated their symptoms of slight discomfort based on their own personal threshold. It is important to note that there are currently no accepted objective measures of DES that have been shown to correlate with symptoms of DES, making the use of an objective measure impossible for this investigation. Further research is needed to establish an objective measure of eye strain that can be used to assess potential treatments for DES. Second, our subjects were not initially screened for DES, meaning that not all subjects developed symptoms of DES from any of the four testing conditions. In the study design, visually “normal” subjects were selected, independent of whether they suffered from DES. The benefit to this is that this study could be more broadly applied to the student population, not just those with consistent symptoms of DES. However, it also prevented assessment of a more uniform cohort in which each all 30 subjects suffered from DES (although the degree of disability would still probably have varied within the subject population).

Although the Clouclip provided significant volumes of data including an accurate measure of working distance every 5 seconds, as discussed in Doron et al. (2023), the device naturally goes into a “sleep” mode and stops collecting data if a 40 second period passes without subject movement. There were many subjects for whom minutes of data were missing due to this feature of the device. Although there was still sufficient data for analysis, any loss of data is unfortunate and could potentially be avoided if the “sleep” feature of the device could be turned off.
Future Directions

Further investigations should aim to evaluate why cognitively demanding tasks induce more subjective symptoms of DES. To explore this, objective testing of visual function (such as accommodative lag and ocular alignment) both during and after the task could be used to determine whether the symptoms are truly visual in origin, or rather if the perceived difficulty of the task is related to the development of symptoms of DES on a psychological basis. Additionally, further investigations should aim to establish the impact of the task on DES symptoms to evaluate if another aspect of the task itself, rather than cognitive demand, plays a role in the development of DES symptoms.
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