EFFECTS OF CORRECTING FIXATION DISPARITY ON DIGITAL EYE STRAIN

By: Sanjana Saksena, B.S.

M.S. Thesis Research Paper

In partial satisfaction of the requirements for the degree of

Master of Science in Vision Science

State University of New York State College of Optometry

February, 2022

Approved by M.S. Thesis Committee:

Dr. Joan K. Portello (Chair)
Dr. Mark Rosenfield
Dr. Suresh Viswanathan

Stewart Bloomfield, Ph.D.
Associate Dean
ABSTRACT

Digital Eye Strain (DES) is a widespread and highly prevalent condition whose incidence appears to be rising during the present pandemic. It comprises a range of visual and ocular symptoms which occur after viewing a digital screen for an extended period of time. Previous work from our laboratory has shown the magnitude of fixation disparity to be the only clinical parameter that is significantly correlated with DES symptoms. Therefore, this study sought to determine whether correcting the underlying fixation disparity will significantly reduce DES symptoms. Thirty young, visually-normal students were required to read randomly generated words from a digital tablet device for 20 minutes. Three different trials were performed, with the subject wearing either: (i) the prism that corrected their fixation disparity, (ii) the same magnitude of prism as for condition (i) but with the opposite base direction or (iii) a near addition lens that corrected the fixation disparity. Immediately after the reading task, subjects rated their ocular and visual symptoms on a questionnaire. There was no significant difference between the mean symptom scores for the three conditions. However, this may be due, in part, to the small number of subjects encountered with large values of fixation disparity. Future studies should further examine the range of oculomotor responses associated with DES in order to provide appropriate treatment options.
INTRODUCTION

Digital Eye Strain

The use of digital devices has become almost universal for both professional and social purposes. Viewing electronic screens, ranging from desktop computers used occupationally to handheld smartphones or tablets used for leisure, has significantly increased contemporary visual demands. Digital Eye Strain (DES), also known as computer vision syndrome, is the collective term for the range of ocular and visual symptoms experienced while viewing a digital screen for extended periods of time (Sheppard and Wolffsohn, 2018). This can result in a range of stresses on the ocular system such as glare, defocus, accommodation dysfunction, fixation disparity, dryness and discomfort (Hall et al. 2015). In 2013, it was reported that adults in the USA spend a daily average of 9.7 hours looking at digital media (including computers, mobile devices and television: http://adage.com/article/digital/americans-spend-time-digital-devices-tv/243414/), and that number has likely risen since then (https://www.statista.com/statistics/1189204/us-teens-children-screen-time-daily-coronavirus-before-during/). The average digital consumer now owns about four devices, necessitating different working distances, font sizes, viewing angles and light intensity and/or contrast (Chase, 2016). Given the substantial amount of time spent looking at digital screens, viewing these digital displays induces a significantly higher magnitude of ocular and visual symptoms, when compared with viewing hard-copy, printed materials (Chu et al. 2011). In fact, 80% of electronic screen users reported significant symptoms during and immediately after viewing digital screens. In a study of computer users in
New York City, it was reported that 40% of subjects experienced tired eyes, 32% experienced dry eye and 31% reported eye discomfort, all at the frequency of ‘at least half the time’ (Portello et al. 2012). Therefore, understanding the underlying cause, physiology and potential treatments of DES will help clinicians provide patients with optimal visual comfort, as well as increased productivity in computer-heavy occupations.

Symptoms of DES have been described as internal or external (Sheedy et al. 2003). Internal symptoms such as strain or ache/headache behind the eyes have been associated with accommodative/binocular vision stress or uncorrected astigmatism (Collins et al. 1990), while external symptoms such as irritation are associated with dry eye (Sheedy et al. 2003). The diagnosis of DES can be improved by incorporating current and realistic visual demands into the standard eye examination (Rosenfield 2016), as well as for computer use (Bali et al. 2014). It is imperative to question patients about digital device usage and assess visual as well as ocular symptoms during the eye examination (Aakre et al. 2007). When probing for more precise causes of DES, it has been suggested that uncorrected refractive error (including presbyopia), accommodative or vergence anomalies, blink patterns, intense light exposure, close working distances and smaller font size could be associated with DES (Coles-Brennan et al. 2019).

Since the underlying cause of DES may vary dramatically, a holistic approach in managing the condition should be tailored to each individual (Bali et al. 2014). Interestingly, headaches and tired eyes, two of the most widely reported symptoms, were found to be less common when digital screens were held beyond 50cm, but were more frequent with increased duration of computer use (Shantakumari et al. 2014). The main strategy found to manage DES has been prevention (Coles-Brennan et al. 2019). This
includes routine eye care and treatment for visually related disorders such as dry eye disease or vergence anomalies, as well as implementing an ergonomic work environment, with an emphasis on high-risk candidates for DES, such as contact lens wearers and computer workers. An ergonomic work environment may include reducing direct proximity with air-conditioning vents or avoiding exposure to high-setting heaters in a poorly ventilated space, having adequate lighting, blue-blocking or anti-reflective coatings, as well as adopting a preferred working distance (Jaschinski et al. 1998).

Frequent and complete blinking, artificial tears, optical tints or blue-light blocking filters, as well as correcting accommodation or vergence anomalies are additional propositions that might relieve DES, although there is little supporting evidence for the use of filtering lenses (Coles-Brennan et al. 2019).

Fixation Disparity

When testing to determine which, if any, clinical measurements were associated with DES symptoms, the only parameter that showed a significant correlation with symptoms was the baseline fixation disparity (Cherny et al. 2019). Fixation disparity is defined as the deviation of images away from corresponding retinal points while maintaining binocular single vision (Evans, 2002). In contrast, heterophoria is defined as the relative position of line of sight when the eyes are dissociated, meaning without an adequate stimulus to fusion (Evans, 2002). Heterophoria can be further classified as exo, when eyes are over diverged and eso, when eyes are over converged relative to the primary position of gaze. The associated phoria is the amount of prism required to move the retinal images onto corresponding retinal points, i.e., to eliminate the fixation
disparity. Therefore, dissociated phoria differs from the associated phoria due to the absence of an adequate stimulus to fusion for the former condition.

When exploring these parameters, previous investigations looking at the relationship between DES symptoms and ocular vergence have reported mixed findings. For example, a number of studies reported no significant change in heterophoria or fixation disparity, either at near or distance, after a working period in an office setting (Rosenfield, 2011; Jaschinski, 1993). A large-scale investigation noted symptoms after computer use, but no association with binocular function over a six-year period of monitoring convergence and heterophorias in computer users (Cole et al. 1996). In contrast, Watten et al. (1994) observed that screen use decreased the ability to converge and diverge appropriately after eight hours of computer work. In an additional investigation, it was noted that DES was significantly worse in subjects with zero fixation disparity when compared with those who had an exo associated phoria (Rosenfield, 2011). The mean associated phoria for subjects who reported the least and greatest discomfort during the task was 1.55Δ exo and ortho, respectively (Rosenfield, 2011). In support of the notion that an exo fixation disparity is desirable, Cherny et al. (2019) showed that symptoms were highest for subjects with eso fixation disparity, implying that over-convergence could be a plausible cause of DES. Accordingly, the optimal management of vergence anomalies may be to leave a small amount of exophoria, rather than making the subject orthophoric (Coles-Brennan et al. 2019). Therefore, the primary aim of this study was to determine whether correcting fixation disparity will alleviate symptoms of eyestrain. Any association between associated phoria and DES symptoms
will help strengthen evidence that it is associated with vergence anomalies, and could provide an option to attenuate the very high prevalence of DES.

METHODS

The experiment was performed on 30 optometry or graduate students at the SUNY College of Optometry (23 females, 7 males) between 22 and 29 years of age. All subjects had best-corrected visual acuity of logMAR 0.0 or better at distance and near in each eye and binocularly, as well as no history of strabismus or ocular disease. All subjects provided written informed consent following a full explanation of the experimental protocol. The study conformed with the Declaration of Helsinki, and was approved by the Institutional Review Board at the SUNY College of Optometry.

This study comprised three sessions, each of which was separated by at least 24 hours. Subjects were asked to refrain from looking at near targets such as their smartphones or other digital screens for at least 5 minutes before starting the experiment to allow the effects of any previous near-vision activities to dissipate. Subjects wore their habitual refractive correction (in the form of spectacles or contact lenses) throughout the session, and the same correction was worn for all 3 trials.

The initial step of the first session was to measure the associated phoria (i.e., prism to correct the baseline fixation disparity). A Saladin Near Point Balance Card (www.Bernell.com/product/BCSALCD/) was used to measure fixation disparity at a distance of 40cm while the target was viewed through cross polarized filters. After identifying the direction of the fixation disparity (i.e., eso or exo), trial case prisms were introduced before the right eye, until the minimum prism that made the Vernier targets
appear to be in precise vertical alignment was determined. The magnitude (in Δ) and
direction (base-in or base-out) of prism required indicated the horizontal associated
phoria. Similarly, convex or concave trial lenses in increments of 0.25D were added to
determine an additional lens that would precisely line up the Vernier targets on the
Saladin card. Plus and minus lenses were used if the subject was determined to have eso
and exo fixation disparity, respectively.

Subjects were then required to perform a 20-minute reading task from an Apple
iPad tablet computer MD529LL/A (www.apple.com). The task comprised reading aloud
a series of randomly ordered words, taken from the first and last words of a non-scientific
novel. The size of a lowercase letter without ascenders or descenders was 1.76 mm, and
contrast was approximately 90%. Targets were presented using single spaced, black-on-
white, 10-point Times-New-Roman font using Microsoft Word software
(www.microsoft.com) (see Figure 1).
For the three conditions, subjects read the material either: (i) through the associated phoria correcting prism, (ii) through a prism with the same magnitude as in condition (i), but with the opposite sign (i.e., base-in rather than base-out or vice versa) or (iii) through the near addition lens that eliminated the baseline fixation disparity. Prisms or near addition lenses were mounted before the eyes in a trial frame while the subjects placed their chin on a chinrest 40cm away from the iPad under uniform, bright illumination. The order of the three sessions was counterbalanced across subjects.

Immediately after each reading session, subjects were presented with a questionnaire that asked about ocular or visual symptoms experienced during the trial. Subjects were asked to rate symptoms on a scale from zero to ten, ten being most severe,
and five representing a moderate response. This questionnaire (Figure 2), derived from Hayes et al. (2002), has been used in a number of studies in our laboratory and shown to be repeatable. The total symptom score (maximum = 100) was determined for each experimental session.

**Figure 2. Post-task questionnaire.**

**RESULTS**

The mean post-task symptom scores for each of the three testing conditions are shown in Figure 3. One-factor analysis of variance indicated no significant difference between these mean values (F= 0.21, df = 2.86, p = 0.81). Similarly, a one factor analysis of variance was performed for the nine subjects having fixation disparity magnitude greater than $2\Delta$ (F = 0.06, df = 2.24, p = 0.94). This is shown in Figure 4.
Figure 3. Mean values of post-task symptom score for the 3 conditions tested. Error bars indicate 1 standard error of the mean (SEM).

Figure 4. Mean values of post-task symptom score for the 3 conditions tested for those individuals having an associated phoria ±2Δ. Error bars indicate 1 standard error of the mean (SEM). Mean symptom scores were: correcting prism = 34, non-correcting prism = 31.67, ADD = 34.89.

In order to demonstrate the range of responses, the data illustrated in Figure 3 is also presented as a box and whisker plot as shown in Figure 5.
Figure 5. Post-task symptom scores for each of the 3 conditions, shown as a box and whisker plot. The spread of data is shown by the top and bottom of the error bars, while the horizontal line within the box represents the median value. The top edge of the box is the third quartile, the bottom edge of the box is the first quartile, and ‘x’ is the mean.

The change in symptom score for each subject, plotted as a function of the baseline associated phoria, is illustrated in Figure 6. Linear regression analysis indicated no significant association \( (r = 0.06, r^2 = 0.004, p = 0.76) \). The change in symptom score for each subject, plotted as a function of the near addition lens required to eliminate the fixation disparity, is illustrated in Figure 7. The mean power of additional lenses used to eliminate fixation disparity was +0.31 D with a standard deviation of 0.89 D. Linear regression analysis indicated no significant association \( (r = 0.13, p = 0.51) \). Mean values (from a range of 0 to 10) for each individual reported symptom in the three test conditions are shown in Table 8. One-factor analysis of variance indicated no significant differences between the three test conditions.
Figure 6. The change in symptom score for each subject, plotted as a function of the baseline associated phoria (AP).

Figure 7. The change in symptom score for each subject, plotted as a function of the near addition lens required to eliminate the fixation disparity.
<table>
<thead>
<tr>
<th>Symptom</th>
<th>Base-in</th>
<th>Base-out</th>
<th>Add</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blurred vision while viewing text</td>
<td>2.47 (0.43)</td>
<td>2.97 (0.52)</td>
<td>3.69 (0.57)</td>
<td>0.30</td>
</tr>
<tr>
<td>Blurred vision when looking into distance</td>
<td>2.87 (0.48)</td>
<td>2.27 (0.47)</td>
<td>3.28 (0.56)</td>
<td>0.19</td>
</tr>
<tr>
<td>Difficulty in refocusing eyes</td>
<td>2.70 (0.46)</td>
<td>2.03 (0.37)</td>
<td>2.97 (0.52)</td>
<td>0.33</td>
</tr>
<tr>
<td>Irritated/burning eyes</td>
<td>3.10 (0.60)</td>
<td>3.43 (0.54)</td>
<td>2.71 (0.54)</td>
<td>0.74</td>
</tr>
<tr>
<td>Dry eyes</td>
<td>3.70 (0.56)</td>
<td>3.30 (0.53)</td>
<td>3.76 (0.53)</td>
<td>0.78</td>
</tr>
<tr>
<td>Eyestrain</td>
<td>4.17 (0.54)</td>
<td>4.43 (0.59)</td>
<td>4.69 (0.57)</td>
<td>0.84</td>
</tr>
<tr>
<td>Headaches</td>
<td>1.37 (0.41)</td>
<td>1.83 (0.48)</td>
<td>1.72 (0.52)</td>
<td>0.71</td>
</tr>
<tr>
<td>Tired eyes</td>
<td>4.23 (0.54)</td>
<td>4.87 (0.53)</td>
<td>4.86 (0.49)</td>
<td>0.71</td>
</tr>
<tr>
<td>Sensitive to light</td>
<td>1.53 (0.39)</td>
<td>1.23 (0.34)</td>
<td>1.83 (0.52)</td>
<td>0.60</td>
</tr>
<tr>
<td>Discomfort in eyes</td>
<td>3.93 (0.57)</td>
<td>4.27 (0.53)</td>
<td>4.31 (0.55)</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 8. Mean values for each individual reported symptom in the three test conditions. p-values were calculated from a one-factor analysis of variance. Figures in parentheses indicate 1 standard error of the mean (SEM).

DISCUSSION:

The results of this study showed that correcting fixation disparity either with prisms or near addition lenses did not produce a significant reduction in symptoms of DES. However, it should be noted that of the 30 subjects tested, only nine had an absolute associated phoria value greater than 2Δ, and only six had an absolute associated phoria value greater than 3Δ. Therefore, the sample size of subjects with large amounts of baseline fixation disparity was extremely small. Nevertheless, even for those individuals having the largest amounts of associated phoria, there was no evidence of a shift in symptom score (Figure 3).
Jaschinski-Kruza (1993) established that fixation disparity for a given viewing distance can only be measured accurately if retinal correspondence is normal in the subject. Retinal correspondence changes physiologically for different viewing distances, alluding to increases in fixation disparity if the viewing distance is altered. Therefore, repeatability of this parameter varies with the viewing distance, although importantly, the best repeatability was found for a viewing distance of 40cm, which was the value used in the present study. Testing at closer viewing distances resulted in an increase in fixation disparity, accommodative error and exophoria.

The repeatability of fixation disparity measurements also varies with the device used to obtain the measurement. Alhassan et al. (2015) found different results for various fixation disparity measuring devices, bringing into question whether this parameter can be used to obtain a reliable and repeatable measure of eye strain. The Wesson card was found to be the best device to measure horizontal disparity at near, whereas the Sheedy disparometer was found to be the least reliable instrument at both near and distance; the Saladin card, i.e., the measurement device used in this study, fell in between these two instruments. More recently, Parmar et al. (2019) tested the repeatability of a Mallett unit, finding that it performed reasonably well in detecting symptomatic individuals and determining a prismatic correction. However, when quantifying horizontal fixation disparity, agreement between the Mallett unit and an iPad fixation disparity instrument was poorer than for vertical misalignment, indicating another area of discrepancy when using different devices for the measurement of fixation disparity to assess eye strain. This large variability limits the ability to identify symptomatic subjects accurately. Thus,
correcting fixation disparity may not be an effective treatment for reducing DES symptoms unless it can be measured in a reliable and consistent manner.

Alhassan et al. (2015) also used the Saladin card to measure associated phoria (as was done here) in their assessment of test repeatability. They found a moderate shift where repeatability was worse only with symptomatic subjects, while Corbett and Maples (2004) significantly found poor Saladin card repeatability between sessions with both symptomatic and asymptomatic optometric students. This was attributed to the wider range of prismatic step changes (1Δ) used by Corbett and Maples (2004) when measuring for fixation disparity compared to the 0.25Δ step changes used by Alhassin et al. (2015). While the present study also used 1Δ steps to measure associated phoria and optometric students as subjects, they were largely asymptomatic with very low values of associated phoria in the present investigation.

Cherny et al. (2019) found a significant correlation between eso fixation disparity and symptom score, suggesting that DES symptoms could be caused by overconvergence on a near object. This overconvergence was not found in the present investigation. Another factor to consider is that the reading task duration used in Cherny et al. and in the present investigation was 20 minutes long. Lengthening the duration of the task could have induced changes in the oculomotor response (i.e., accommodation and vergence) potentially leading to greater DES symptoms. Interestingly, Tosha et al. (2009) proposed that visual discomfort elicited by digital strain is more likely due to accommodative fatigue rather than accommodative insufficiency. The 20 minute task duration used in the present study might not have been long enough to elicit symptoms of visual fatigue in the present subjects. Had the task been extended from 20 to 60 minutes, then subjects may
have become more sensitive to visual fatigue, resulting in changes in the accommodative response and perhaps even visual acuity (Chi and Lin, 1998). However, a 20-minute task duration was selected here because previous studies have shown that it is sufficiently long to induce significant symptoms (Lampton et al. 1994; Rosenfield et al. 2010; Chu et al. 2011). Indeed, Lampton et al. (1994) noted that 61% of subjects experienced symptoms after 20 minutes of virtual screen exposure, of which the greatest symptoms were experienced at the 20-minute mark. Additionally, this was the task duration adopted by Cherny et al.

Since the results presented here indicate that correcting fixation disparity had no significant impact on DES symptoms, variations in the vergence response may not be the primary cause of the discomfort experienced when viewing electronic screens. Alternatively, other vergence parameters such as the relative vergence ranges or vergence amplitude (near point of convergence) may provide different answers with regard to the underlying cause of DES. The interactions of accommodation and vergence may also change during the course of a sustained computer task. Watten et al. (1994) reported substantial changes in oculomotor functions in employees who did sustained work at near. They also found significant reductions in positive relative accommodation (PRA), negative relative accommodation (NRA), positive relative convergence (i.e., base-out vergence range) and negative relative convergence (i.e., base-in vergence range) at the end of the day. Of these parameters, 60% of the overall oculomotor functions post-task were accounted for by changes in the vergence ranges, which were assessed by increasing base in and base out prism, until blur was reported. However, Rosenfield et al. (2010) observed a significant increase in binocular accommodative facility concurrent with
greater post-task symptoms, although no significant changes in monocular accommodative facility or vergence facility findings were seen after a 25-minute digital task. Looking at the accommodative component in the present study, the average additional lens power to eliminate fixation disparity among the 30 optometry students was +0.31D with a standard deviation of 0.89. Even then, the changes in pre-task to post-task symptom scores were minimal to none (figure 7). According to Koh et al. (2020), adding a low-add bifocal design contact lens which adds a +0.50D near additional power alleviates accommodation while providing clear and comfortable vision in the distance for non-presbyopes. While adding a low-plus lens correction for near vision is proven to relax the stimulus to accommodate, a potential contributing factor to eye strain, Koh et al. (2020) only tested this objectively, and subjective measures of whether these subjects were less symptomatic with the low-additional lenses were not assessed. Yammouni et al. (2020) used the Computer Vision Syndrome Questionnaire, a similar questionnaire to that used in the present study, to test the effects of a low additional convex lens subjectively. Those in the age group between 26 and 30 years old significantly preferred +0.75 D lens over their habitual distance correction for near tasks. The additional lenses in the present investigation differed from these findings in that the average additional lens was much lower than +0.75 D and the post-task survey did not indicate a significant reduction in symptoms with additional lenses. Perhaps a higher amount of convex add at near would yield less symptomatic of eye strain, and this can be further evaluated in a future study with respect to reported symptoms as a quantitative measure of preference. However, it must be acknowledged that the eye strain may not be equally induced by internal and external factors. Rosenfield et al. (2010) noted a significant positive correlation between


asthenopia and both vergence facility and dry eye symptoms. The authors felt that DES symptoms in those subjects were more likely to be caused by dry eye rather than accommodative or vergence disparities. A future study should examine the relationship between DES symptoms and all aspects of binocular function, rather than just ocular alignment, i.e., fixation disparity.

Overall, it is important to identify the underlying cause of DES, due to its high prevalence in modern society as the demand for digital screen use continues to increase. Identifying the underlying causes will allow viable treatment options to be developed.

REFERENCES:


Collier JD, Rosenfield M. Accommodation and convergence during sustained computer work. Optometry 2011; 82: 434-40.


