Summer 8-29-2019

Visual Fatigue and the Corresponding Changes on the Accommodative System after Digital Viewing

Khawlah Alfaifi
Pacific University

Yu-Chi Tai
Pacific University

Scott Cooper
Pacific University

Paula Luke
Pacific University

Recommended Citation

Alfaifi, Khawlah; Tai, Yu-Chi; Cooper, Scott; and Luke, Paula, "Visual Fatigue and the Corresponding Changes on the Accommodative System after Digital Viewing" (2019). *College of Optometry*. 1581.
https://commons.pacificu.edu/opt/1581

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Abstract

Purpose

Visual fatigue symptoms are associated with a reduction in accommodative performance. The study aimed to understand the impact of near viewing on visual fatigue and the accommodative system. A custom-made program was created for the free-space facility test to objectively measure dynamic changes of the accommodative accuracy and stability and obtain response accuracy and reaction time.

Methods

Real-time measurements of accommodation were obtained with an open-field autorefractor from 23 young adults while reading and performing a free-space facility test (targets at 500 and 25 cm) using a computer program which measured subjects' Reaction Time (RT), response accuracy, and accommodative accuracy and stability while maintaining focus at the targets for 8 seconds. In a crossover design, each subject performed a fatigue-inducing task (digital gaming) for 25 minutes in three viewing conditions tested on three different days: near-binocular (NB), far-binocular (FB), near-monocular (NM). Pairwise comparison was conducted to compare visual discomfort rating, RT, response accuracy, accommodative, and pupillary measurements before and after gaming. Mixed-Model ANCOVA was used to compare the effects of the fatigue-inducing task (Conditions), symptomatic vs. asymptomatic group (Group), post-task order (Order), and their interactions on all target measurements with the pre-test measurement as covariate.

Results

After the fatigue-inducing task, subjective discomfort rating on Visual Discomfort Survey (VDS) increased significantly (P = P P= .001), and facility at near (P = .001). The overall score of VDS was significantly different between conditions (P = 0.04) with higher discomfort rating after the NB condition. In the facility test, accommodative instability was higher after FB than after NB and NM with both far facility (P = .03 and .04, respectively) and near facility (P = .004 and .001, respectively) tasks. The symptomatic group showed higher pupillary (P = .002) and accommodative (P = .04) instability than the asymptomatic group at near facility. At near facility, pupil size and accommodation were more unstable under the 2nd post-task order (free-space facility then reading) than under the 1st post-task order (reading then free-space facility).

Discussion

Increased VDS total score after the fatigue-inducing task partially supported our hypothesis that sustained near viewing of digital devices would cause visual discomfort though we cannot attribute the effect to the accommodative system alone. Consistent with previous findings, pupil diameter decreased significantly after the fatigue-inducing task in both tests (reading and facility); however, no accommodative changes were observed. It is possible that the effect of the fatigue-inducing task was not strong enough to change all oculomotor functions; still, the pupil constricted increasing the depth of focus, but without a measurable change in accommodative power. The finding that higher subjective discomfort was reported after NB than after NM suggests that the involvement of both near-focusing (accommodation) and binocular coordination (convergence) is more stressful than the accommodative system alone. Similarly, it’s more challenging for an anomalous oculomotor system to cope with visual stress, which may explain the finding of the higher pupillary and accommodative instability with the symptomatic group compared to the asymptomatic group, especially when the test occurred immediately after the fatigue-inducing task.

Conclusions

Even with brief near digital viewing, visual discomfort significantly increased as measured by VDS in all subjects. This impact was more evident in symotomatic subjects. The pupillary response seemed to readily respond when following the fatigue-inducing task. The effect of the visual stress was stronger among symptomatic subjects and was manifest clearly when measured immediately after the fatigue-inducing task. Interruption from other tasks may mitigate the effect of near-viewing stress to the oculomotor system and make it harder to diagnose. No accommodative changes were observed except the increment of accommodative instability among symptomatic subjects during the dynamic facility test. The free-space facility program, created for this study, allows accurate assessment of the subject's response accuracy, RT, and accommodative dynamics (speed, accuracy, and stability of response) when shifting focusing distances in a naturalistic environment. Future studies should consider an increase in the fatigue-inducing level and duration which may elicit more changes in the accommodative system to aid in understanding accommodative behavior under visual stress. With a simple modification of the testing protocol (such as the fixation time), the program will allow for assessment of different components in the oculomotor models.

Keywords

Visual fatigue, Accommodation, Free-space accommodative facility, Accommodation stability

Degree Type
Thesis

Degree Name
Master of Science in Vision Science

Committee Chair
Yu-Chi Tai

Second Advisor
Scott Cooper

Third Advisor
Paula Luke

Keywords
Visual fatigue, Accommodation, Free-space facility, Accommodation stability

Subject Categories
Optometry

VISUAL FATIGUE AND THE CORRESPONDING CHANGES ON THE ACCOMMODATIVE SYSTEM AFTER DIGITAL DEVICES USE

by

KHAWLAH ALFAIFI

A THESIS

Submitted to the Graduate Faculty of Pacific University Vision Science Graduate Program,
in partial fulfillment of the requirements for the degree of
Master of Science
in
Vision Science

PACIFIC UNIVERSITY
FOREST GROVE, OREGON

August, 2019

MS Thesis Committee:

Associated Professor Yu-Chi Tai, Thesis Advisor & Committee Chair
Associated Professor Scott Cooper, Committee member
Associated Professor Paula Luke, Committee member

PACIFIC UNIVERSITY OREGON COLLEGE OF OPTOMETRY
VISION SCIENCE GRADUATE COMMITTEE

This thesis of *Khawlah Alfaifi, titled "***Visual Fatigue and the Corresponding Changes on the Accommodative System After Digital Devices Use***",* is approved for acceptance in partial fulfillment of the requirements of the degree of Master of Science.

____
Accepted Date

Signatures of the Thesis Committee:

____
Thesis Advisor: Yu-Chi Tai, PhD
Pacific University College of Optometry

____
Thesis Committee: Scott C. Cooper, OD
Pacific University College of Optometry

____
Thesis Committee: Paula Luke, OD
Pacific University College of Optometry

____ *Date:*___________
Director of the Vision Science Graduate Program: Yu-Chi Tai, PhD

ABSTRACT

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KHAWLAH ALFAIFI

MASTER OF SCIENCE IN VISION SCIENCE
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Results

After the fatigue-inducing task, subjective discomfort rating on Visual Discomfort Survey (VDS) increased significantly (*P* = <.0001). Accommodative response and its stability did not differ significantly before and after the fatigue-inducing task in both reading and facility tests; however, pupil size diameter decreased significantly in reading (*P* <.0001), facility at far (*P*= .001), and facility at near (*P* = .001). The overall score of VDS was significantly different between conditions (*P* = 0.04) with higher discomfort rating after the NB condition. In the facility test, accommodative instability was higher after FB than after NB and NM with both far facility (*P* = .03 and .04, respectively) and near facility (*P* = .004 and .001, respectively) tasks. The symptomatic group showed higher pupillary (*P* = .002) and accommodative (*P* = .04) instability than the asymptomatic group during the fixation period of the near facility test. Also during the near facility fixation period, pupil size and accommodation were more unstable under the 2nd post-task order (free-space facility then reading) than under the 1st post-task order (reading then free-space facility).

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Increased VDS total score after the fatigue-inducing task partially supported our hypothesis that sustained near viewing of digital devices would cause visual discomfort though we cannot attribute the effect to the accommodative system alone. Consistent with previous findings, pupil diameter decreased significantly after the fatigue-inducing task in both tests (reading and facility); however, no accommodative changes were observed. It is possible that the effect of the fatigue-inducing task was not strong enough to change all oculomotor functions; still, the pupil constricted increasing the depth of focus, but without a measurable change in accommodative power. The finding that higher subjective discomfort was reported after NB than after NM suggests that the involvement of both near-focusing

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Keywords

Visual fatigue, Accommodation, Free-space accommodative facility, Accommodation stability

ACKNOWLEDGEMENT

I would first like to thank my advisor, Dr. Yu-Chi Tai, for her enthusiasm, dedication, and guidance that helped me in the time of research and writing this thesis.

Also, I would like to thank my committee members, Dr. Scott C. Cooper, and Dr. Paula Luke whose expertise was invaluable in the formulating of the research topic and supporting me throughout the writing of this thesis.

I would like to acknowledge Dr. John Hayes support in providing me advice on the data analysis.

I would particularly thank my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. Also, I would like to thank my elder brother, Turky, my sisters, Budoor and Arwa, for their video calls, visits, and their unconditional love.

I would like to thank my friend Amani Alshamrani, for her constant support.

Finally, words cannot express the feelings I have for my younger brother for his constant unconditional support in my study and life in general! Thank you, Ahmad! You are the best!

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LIST OF ABBREVIATIONS

CVS	Computer vision syndrome
AI	Accommodative insufficiency
CI	Convergence insufficiency
CISS	Convergence insufficiency symptom survey
AC/A	Accommodative convergence ratio
CA/C	Convergence accommodative ratio
NRA	Negative relative accommodation
PRA	Positive relative accommodation
MEM	Monocular estimate method
AS	Accommodation stimulus
VS	Vergence stimulus
PS	Proximal stimulus
VDS	Viewing discomfort survey
FB	Far binocular
NB	Near binocular
NM	Near monocular
RT	Reaction time
ES	Effect size
RS	Reading speed

1 Introduction

1.1 Overuse of digital devices

With portability and continuously improved functions of handheld devices, the preference of viewing smartphones and other handheld gadgets over hardcopy materials is evident and has continued to increase.[1] Worldwide, millions of people use the internet every day, spending on average about 6.5 hours online with computer devices – most of the time with smartphones.[2] In fact, more than sixty percent of computer users experience visual fatigue symptoms.[1,3–5] Previous studies have shown that spending four hours or more viewing computer displays significantly increases the level of visual discomforts such as eye strain, red eyes, and blurred vision.[6,7] Because smartphone users tend to have longer use of devices over time at a close-working distance, this places an additional demand on the accommodative system.[1,8] Together, the close viewing distance and the prolonged digital viewing have led to a strong association between the accommodation functions and visual discomfort symptoms.[9,10]

1.2 Visual fatigue

Given the increase in the near-distance workload in today's societies, visual fatigue has gained a lot of attention among clinicians and researchers; however, its underlying mechanism is not yet well explained.[10] Fatigue is a result of one or multiple factors such as medication intake, abnormal health conditions, or even distressing workload.[11] Visual fatigue, in particular, can be originated from a weakness in the oculomotor system, perception, visual stimulus processing, or transmission of neurons.[12] Notably, visual fatigue has been identified as one of the most common complaints among people with oculomotor dysfunctions, and it can manifest as double vision, blurry vision, eye pain, and/or headache.[13] Those symptoms overlap with Computer Vision Syndrome (CVS). The American Optometric Association defines CVS as a group of visual complaints that results from near viewing of computer screens.[14] In a review paper investigating the ocular causes and potential treatments for CVS, Rosenfield states that oculomotor dysfunctions and dry eyes are considered the primary factors in causing CVS.[1] Similarly, Simmers et al. emphasizes the role of oculomotor anomalies among individuals with normal eye health in causing visual discomfort symptoms.[15] Many studies have associated reductions in accommodative function (e.g., lag) to visual discomfort level after near work.[9,10,16]

1.3 Accommodation

1.3.1 Accommodative measurements

Accommodation is the process of adjusting the crystalline lens dioptric power to focus an image on the retina in a range of distances.[17,18] Clinical evaluation of accommodative function includes the amplitude of accommodation, accommodative accuracy (i.e., lag or lead), accommodative facility, and negative/positive relative accommodation.[19]

The amplitude of accommodation is the maximum increase in the dioptric power of the crystalline lens to focus at the nearest point possible.[17] When an individual persistently has an amplitude of accommodation lower than what is expected for their age by about 2 Diopters, they may be diagnosed with *accommodative insufficiency*.[18] The manifestation of an increased accommodative lag after sustained near viewing is referred to as *accommodative fatigue*.[11] Thus, it is important to distinguish between accommodative fatigue and accommodative insufficiency as the former is caused by the inability to maintain a steady-sustain response (i.e., ill-sustained accommodation) while the latter is defined as a constant decrease in the accommodative amplitude of the age-matched normative value.[9,11] Objective measurements of the amplitude of accommodation can be obtained using an autorefractor while subjective measurements can be obtained using the push-up test, or minus-lens method.[20]

Accommodative facility is the speed of reaching a new accommodative demand.[19,20] Whereas, the slowness of changing focus between stimuli of different distances is known as *accommodative infacility*.[19,20] Clinically, this is often measured subjectively using flippers, or other approaches such as with modifications of NRA and PRA methods.[20]

Accommodative accuracy is the individual's ability to sustain eye fixation on the target.[18] One clinical measurement of the accuracy is the Monocular Estimate Method (MEM), a dynamic retinoscopy method .[19] A lag of accommodation is when the accommodative response is less than the accommodative stimulus in dioptric power.[20] On the other hand, a lead of accommodation is when the accommodative response is more than the accommodative stimulus in dioptric power.[20]

1.3.2 Factors that affect accommodation:

Target characteristics. Any image degradation regarding the target characteristics such as low contrast sensitivity, small spatial frequency, or weak luminance will negatively affect the perception of the image which may result in an accommodative response error.[18]

Luminance. Ciuffreda et al. stated that the accommodative system is relatively insensitive to luminance, spatial frequency, and pupil diameter, unless there is a significant variation in those parameters, but strongly affected by the eccentricity of the retinal image and retinal-image motion.[18] However, Wolska and Switula found that imbalanced luminance affects several visual functions, including accommodation. They found a statistically significant effect of ambient luminance on accommodative power, and accommodative amplitude decreased as surrounding luminance increased.[12] Although there was no direct impact of luminance changes on asthenopic symptoms, they suspect imbalanced ambient light will affect the visual functions (such as accommodation) and cause visual discomfort. Therefore, they suggest a luminance ratio of 1:3 (device luminance: ambient/room luminance) to avoid visual discomfort.[12]

1.3.3 Models of the visual system

Hung and Ciuffreda and their colleagues have proposed a series of static (or steady-state) models of the accommodative system explain the wide range of basic accommodative (and vergence) functions and clinical conditions.[21–24] Figure 1 presents a recent version of the steady-static model.[25]

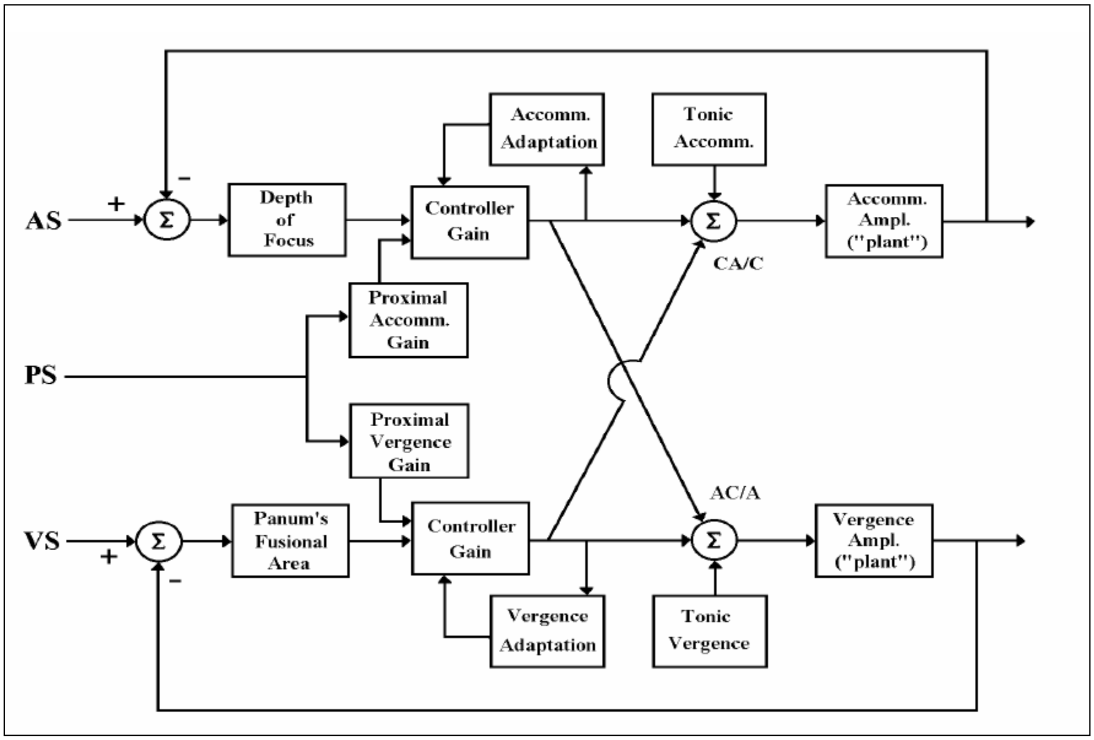


Figure 1. The steady-static model explains the accommodative system and its motor interaction. "Adapted from Models of Accommodation (p.332)."

1.3.3.1 Input

The input (i.e., visual stimulus) of the system can be an accommodative stimulus (AS, i.e., the sensation of blur caused by a visual target at a distance) or a vergence stimulus (VS, i.e., the sensation of disparity between the retinal images of the two eyes).[18] A third stimulus is known as the proximal stimulus (PS), which is the sensation of distance. PS does not have a separate feedback loop; whereas, it emerges simultaneously into the AS and VS feedback loops. Also, PS plays a more significant role under the closed-loop accommodation; however, it plays a minimal role under the open-loop accommodation (i.e., tonic accommodation).

1.3.3.2 Threshold

The threshold for starting an accommodative response is the blur or change in blur determined by the depth of focus while the threshold for starting a vergence response is retinal disparity or a shift of retinal disparity within Panum's fusional area, preventing diplopia.[18,25]

1.3.3.3 Phasic loop (Gain)

This element is responsible for initiating the first response to the stimulus to obtain a clear/fused image, and reducing once a clear single image is achieved and sustained for a period of time.[26]

1.3.3.4 Adaptive loop

Once the phasic loop is activated and sustained at a particular level, the adaptive loop is activated to help maintain the static posture of the system, and it is most prominent during sustained near work.[18,27] Due to its relatively slower time course, it has a reduced rate of decay.[27] Therefore, after sustained near work, such as reading, a brief viewing at far and returning to the near work requires little phasic accommodative activity to return to near viewing with clarity.[25] However, symptomatic individuals with significantly slower decay may present with a delayed accommodative response.[25]

1.3.3.5 Crosslink gain

The crosslink gain is the interaction of the accommodative and the convergence systems.[25] The accommodative convergence is represented by the AC/A ratio while the convergence accommodation is represented by the CA/C ratio. For example, if the accommodation gain was higher, the vergence will be overdriven, which may cause esotropia. On the other hand, if the gain was smaller, exotropia may occur.[18]

The output of these elements continues to the cortex formulating neural signals that innervate the eye structure (ciliary muscles, lens complex, and extraocular muscles) causing the functions of the near triad (accommodation, convergence, and miosis).[18]

1.3.4 The near triad, autonomic nervous system, and visual fatigue

When an image is viewed at a close distance (i.e., AS and VS), three major mechanisms occur in the eye structures to allow the perception of a clear image. The three mechanisms are represented by constriction of the medial recti of the extraocular muscles (i.e., *convergence*), contraction of the ciliary muscles, which increases the anterior lens curvature causing an increase in the lens power (i.e., *accommodation*), and contraction of the sphincter pupillae muscle causing a decrease in pupil size (i.e., *miosis*). Those mechanisms describe the function of the near triad.[28]

The autonomic nervous system has two branches that innervate the oculomotor structures; the *parasympathetic* and the *sympathetic nervous systems*.[18] The activation of the parasympathetic system increases accommodation, and it acts rapidly (response time: 1 second) in the dynamic changes of accommodation.[18] Also, the activation of the parasympathetic system results in pupil constriction.[18] On the other hand, the activation of the sympathetic nervous system causes a reduction in accommodation.[18] Also, the sympathetic system acts relatively slowly (response time: 5-10 seconds) in the dynamic changes of accommodation; therefore, it had been suggested that it is involved in tracking slow-moving objects.[18,29] Thus, the primary purpose of the sympathetic system is to reduce accommodation especially after sustained near viewing; whereas, the parasympathetic system role involves transient activation of accommodative function.[18,30]

The increase in the pupil size constriction[7] has been observed after prolonged viewing of computer screens. These observations have been attributed to the possible spasms of the sphincter pupillae and ciliary muscles, which both are innervated by the parasympathetic system.[7] Thus, accommodation function and the pupil size are important physiological indices in evaluating visual fatigue symptoms after prolonged near work on digital devices.

1.4 Accommodation and visual fatigue

Even though visual fatigue symptoms can be associated with one or more aspects of the visual system, such as tear secretion, retinal functions, or even the central nervous system,[31] the oculomotor dysfunctions have been highly correlated with visual fatigue symptoms.[13] Using the Conlen Survey of Visual Discomfort on 571 college students, Borsting et al. found that 60 percent of the subjects had a broad range of symptoms while 40 percent had discrete symptoms (e.g., headache/soreness or blur/diplopia).[32] More specifically, 46.9% of subjects with high to moderate symptoms had reported blur/diplopia. This finding suggests that one of the main causes of the visual discomfort may be associated with the oculomotor/accommodative systems[32], which is consistent with what Scheiman et al. had indicated.[13]

Indeed, Glasser et al. have observed a reduction of accommodative performance after sustained near work.[9] Tosha et al. found the amount of accommodative lag is highly associated with the level of discomfort symptoms.[10] Moreover, accommodative infacility was found to be one of the most common diagnoses among subjects who complain of CVS.[1] Liu et al. also found a strong association between facility tests and visual discomfort symptoms.[16] However, not all findings support the accommodative system as the main cause of visual discomfort. For instance, Ciuffreda et al.[33] and Simmers et al.[15] observed similar accommodative responses to the stimulus demands between symptomatic and asymptomatic subjects, indicating that there is no difference in accommodative function between the two groups. Similarly, Rosenfield et al.[34] did not find a significant change in accommodative facility after 25 minutes of computer work at 50 cm. The absence of significance was denoted to the short period of near work.[11] The recording time of the accommodative responses, the duration and the distance of the fatigue-stimulating task may limit the finding of significant changes.[10,15,33,34]

The inconsistency on those findings mentioned in the previous paragraph may result from the use of different measurements or procedures among studies. For example, subjective measures of accommodative amplitude with the push-up method were found to be significantly higher than objective measurements using an autorefractor.[35] Similarly, subjective measures of accommodative facility with flippers were also different from measurement obtained with a free-space (i.e., focus-switching) method.[36] Subjective methods rely on the participant's attention, processing, and motor skills. Also, vergence demand is not changing in spite of the changing accommodative demand, which disrupts the synchronization between both systems and causes visual fatigue symptoms.[37] On the other hand, the free-space method of measuring accommodative facility allows a balanced harmony between both systems and accurately reflects the accommodative performance under a more naturalistic viewing condition.[11] A recent study done by Thiagarajan et al.[11] assessed the accommodative performance and the fatigue level before and after performing both facility methods, the free-space, and flippers. They found a significant reduction of accommodative response after the flipper method, and 60% of the subjects reported visual fatigue. Whereas, after the free-space method, none of the subjects reported a fatigue sensation and no significant change was observed in the accommodative response and its stability. These findings encouraged us to employ the free-space method to evaluate the accommodative performance under more naturalistic conditions. A custom-made program was generated to computerize the free-space method and revised with additional features to fit our study purpose.

Visual fatigue symptoms are usually quantified clinically by subjective validated measurements such as the Conlon Survey and Convergence Insufficiency Symptom Survey (CISS).[43] In the current study, we adopted the Viewing Discomfort Survey (VDS, see Appendix A) as the tool of subjective assessment of visual discomfort symptoms. VDS was developed by Sheedy and colleagues through a series of visual discomfort studies.[44] VDS comprised of questions covering most of the possible fatigue causes, including cognitive symptoms, body symptoms, visual symptoms (accommodative- and vergence-related discomfort), dry eye sensation, and the overall tiredness, which includes items that were not mainly related to near vision as in the CISS. (see Appendix F for comparison between CISS and VDS and Appendix G for comparison between Conlon Survey and VDS).

1.5 Research questions and goals of the current study

To the extent of our knowledge, there are no objective measurements that quantify the level of fatigue in the routine clinical exam.[32] Therefore, obtaining objective measures of accommodation and subjective evaluation of visual fatigue symptoms will help in determining the correlations between the two parameters. We expect that after viewing digital devices, the accommodative system will be negatively influenced, which may be consistent with the VDS.

Our primary hypothesis was that sustained viewing of digital devices would result in degradation in the performance of the accommodative system and visual fatigue sensation. Our second hypothesis was that symptomatic subjects would manifest higher drawbacks in the accommodative system function and a worse sensation of visual fatigue than normal subject after near viewing of digital devices.

The current study was aimed to understand the role of the accommodative system on visual fatigue caused by near-distance digital viewing. Subjects' real-time accommodative response was measured while reading from a laptop at near and when switching gaze between near and far targets. These measurements were obtained before and after playing a game app on a smartphone at an up-close viewing distance under naturalistic viewing conditions to reflect the natural behavior of the accommodative system in everyday tasks. The free-space facility test was performed using the custom-made program to measure the change of accommodative power in real-time while subjects switched gazes at different distances. The program captured the dynamic change of accommodative power and recorded response accuracy and efficiency (reaction time) which are not usually assessed in typical clinical settings.

2. Methods

2.1 Subjects

Twenty-four adults (8 males and 16 females, age 18–32 yo, average 26 yo) were recruited from Pacific University and the surrounding community. Subjects were screened for best corrected near and far Visual Acuity (VA) at 20/30 or better, monocularly and binocularly; however, only VA of 20/30 or better on the right eye was considered in the inclusion criteria. A positive response for global stereopsis using Random-dot stereoacuity test was used to check for suppression. Subjects were also screened for reading ability at the 12th-grade level as evidenced by the completion of reading the Visagraph Test Booklet at the 12th grade level with comprehension. Subjects were excluded from the study if they had systemic disease, ocular disease, or were taking medications or supplements that may adversely affect their vergence or accommodative functions. All study procedures were approved by the Institutional Review Board (IRB) of Pacific University. All subjects gave written informed consent in accordance with the Declaration of Helsinki and were compensated for their time financially or with extra course credits if applicable.

All subjects who passed the inclusion criteria proceeded to the testing protocol. Each subject visited the laboratory on three separate occasions: one for each of the three fatigue-inducing game-playing task conditions. The three conditions were presented to the subjects based on a designated Latin-Square order. All 24 subjects except one completed all three visits. Data of the subject who voluntarily withdrew from the study after completion of the first visit was not included in the analysis. With the current sample size of 23, with the power of 0.80, the maximum effect size (ES) that could be obtained is 0.5.

2.2 Material

The Visagraph reading booklet (Taylor Online, Inc., New York City, USA) was used in the screening of the subject's reading level by reading one standard Taylor Level 10 (College) paragraph, followed by ten comprehension questions. A comprehension score of 70% or better was considered a qualification for the subject reading performance.

Convergence Insufficiency Symptom Survey (CISS)[43] was used to categorize subjects into a symptomatic or asymptomatic group. The survey includes 15 items rated on a 5-point scale: (0) never, (1) infrequently, (2) sometimes, (3) fairly often, and (4) always. A CISS score (the sum of the total ratings) of 21 or higher is suggestive of convergence insufficiency. Studies have found that subjects with accommodative insufficiency scored higher than subjects with normal binocular vision.[45,46] The same criteria were used to categorize the subjects into symptomatic or asymptomatic group.

A novel, "*The Moonstone"* by Willkie Collins, was presented as the reading content using a custom-made program built with Experiment Builder software (SR Research, Ontario, CA). The text was displayed with 11-point Calibri font (with 0.23° x 0.23° for letter x) at a viewing distance of 50 cm within a 7.0° x 5.5° window, which is within the accurate tracking range of Grand Seiko.[47]

Viewing symptoms were measured with *the Viewing Discomfort Survey (VDS)*, a 17-question survey rated on a 5-point scale (0: Not at All - 4: Extremely) covering the following areas: cognitive status, body discomfort, perceptual discomfort, and eye discomfort.[5] (Appendix A)

2.3 Apparatus

Distant visual acuities were screened at 6 meters using the Snellen acuity chart presented on an *M&S Smart System* (M&S Technologies, Inc, Niles, IL). Near visual acuities were screened using the *Rosenbaum Pocket Vision Screener* (Graham-Field Health Products, Atlanta, GA) at 40 cm. A *Randot®* *Stereotest chart* (Stereo Optical Co, Chicago, IL) was used to measure subjects' depth perception.

An open-field autorefractor, *Grand Seiko WAM-5500* (Grand Seiko, Hiroshima, Japan), was used to measure the real-time eye accommodation and pupil size of the right eye every 200 milliseconds (i.e., a sampling rate of 5 Hz). Using a serial cable to connect the autorefractor to a laptop (ASUSTeK Computer Inc., Taipei, Taiwan), the *WCS-1* data collection software provided by Grand Seiko recorded the real-time accommodative data and saved it to an Excel file. Another laptop (ASUSTeK Computer Inc., Taipei Taiwan) with a resolution of 1920 x 1080 was used to display the reading test while real-time measurement of accommodation was recorded.

An iPhone 8 (Apple Inc., California, USA) of a screen size of 4.7 inches (resolution of 1334 x 750, 326 ppi) was employed to perform the fatigue-inducing task at a near distance of 25 cm (angular size 13.27° x 21.80°). A TV (SAMSUNG model #, Seoul, South Korea) of a screen size of 55 inches (resolution 1920 x 1080, 40 ppi) was employed to display the far target during facility testing and to perform the fatigue-inducing task at a far distance of 5 meters (angular size 13.62° x 7.74°).

Average luminance of the displaying devices was measured using Photo Research SpectraScan photometer (PR 670): 54,191 cd/m^2 for iPhone 8 used for near-distance game-playing, 106,255 cd/m^2 for Samsung 3D TV used for far-distance game-playing, 88,774 cd/m^2 for Asus laptop used in the far facility test, 14,052 cd/m^2 for the hardcopy target with the near facility test, and 54,797 cd/m^2 for Asus laptop used for reading. The auto-brightness feature of all devices was disabled.

2.4 Procedure

After confirmed eligibility to the study, subjects proceeded to the tasks of the first visit:

- Pre-fatigue-inducing test: a 5-minute reading, free-space accommodative facility test (2.5 minutes) and viewing discomfort rating.
- Fatigue-inducing task (25 minutes): one of the three game-playing conditions used to induce visual fatigue
- Post-fatigue-inducing test: same as the pre-fatigue-inducing test

The same procedures were repeated for the other two visits with the difference of the fatigue-inducing task. Subjects were tested individually in a quiet room (6 x 2 meters*)* with regular office lighting (580 lux). They had to complete all three visits to fulfill the purpose of this study.

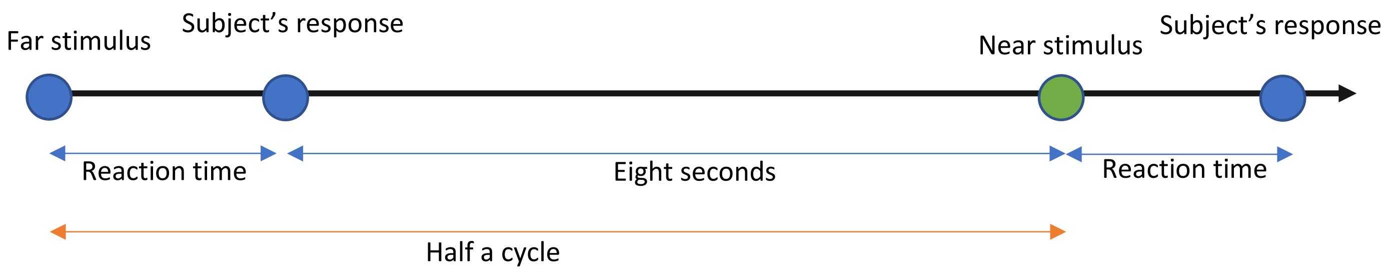
2.4.1 Pre-fatigue-inducing tests

2.4.1.1 Reading

The subject read a story presented on a laptop at a 50-cm viewing distance for five minutes. They were asked to rest their chin on the chinrest and lean their forehead against the forehead rest of a Grand Seiko autorefractor which recorded the real-time accommodative response and the pupil size. The text was presented with a custom-made program which also recorded the reading speed.

2.4.1.2 The free-space accommodative facility test, phasic accuracy, and stability

Accommodative facility was measured with a custom-made program (the *Free-space Accommodative Facility Testing Program*) with a far target (a Tumbling E, angular size 0.21° x 0.21°) presented at 500 cm on a laptop screen and a near target (a printed letter “E”, angular size 0.21° x 0.21°) on a stick at 25 cm from the subject’s right eye. Using a screen to present the near target would obstruct the view to the far target; therefore, we used a small fixed target. Before initiating the facility test, a calibration page was used to ensure that both targets, far and near, were aligned in front of the subject’s right eye to be readily measured by the automated autorefractor. The program displays eight cycles of facility stimuli with near and far targets fixation in each cycle controlled by a computerized voice command (“NEAR” or “FAR”) that occurred every eight seconds. As illustrated in the test diagram bellow, the response to each command contained two phases: adjusting accommodation and sustaining fixation until the next command. When adjusting accommodation to the far target distance, subjects were asked to identify the orientation of the tumbling E using the arrow keys on a wireless keyboard. The orientation of the target was randomized in real-time by the program. The subject’s reaction time (the indicator of accommodative facility) and response accuracy were recorded by the program. After response, the subject remained fixating at the target for a total of eight seconds (the sustained-fixation phase) to measure phasic accommodative accuracy and stability. The total testing time for this task was about 2 and half minutes.



2.4.1.3 *Viewing Discomfort Survey (VDS)*

The subject's discomfort level was subjectively obtained using the VDS at the end of the pre-fatigue-inducing test. On a scale of 0 to 4, the subject rated their level of discomfort with 0 = no symptoms of discomfort, 1 = mild discomfort, 2 = moderate discomfort, 3 = severe discomfort, and 4 = extreme discomfort.

2.4.1.4 *Fatigue-inducing tasks*

Subjects played a series of games from a brain-training application (*Lumosity*) on an iPhone. These games engaged subjects with different cognitive and/or perceptual functions such as reading comprehension, spatial recall, information processing, working memory, and face-name recall, etc. Three viewing conditions were adopted to manipulate different levels of fatigue symptoms:

- Near Binocular viewing condition (NB): subjects played the brain-training games presented on a smartphone (iPhone 8) at a viewing distance of 25 cm for 25 minutes. The subject had to look at the phone with both eyes open.

- Near Monocular viewing condition (NM): the gaming task was the same as the binocular-near viewing condition except the subject had to look at the phone with only the right eye while the left eye was covered by a patch.
- Far Binocular viewing condition (FB): subjects played the brain-training games presented on a TV at a viewing distance of 500 cm for a continuous 25 minutes period. The subject had to look at the TV with both eyes open.

2.4.2 Post-fatigue-inducing tests and orders

The same three tests in the pre-fatigue-inducing period were administered after the fatigue-inducing task. However, the order of the reading and the facility test was randomized among visits, and the variables were analyzed accordingly. The test sequence starting with the reading test immediately after the fatigue-inducing task was referred to as "order 1" while the test sequence starting with the facility test was referred as "order 2".

2.5 Measurements

2.5.1 Viewing discomfort symptoms

Subjects' subjective rating of discomfort was established using the VDS, and was recorded by a custom-made program and were analyzed by individual items.

2.5.2 Reading speed and reading comprehension

Reading speed was calculated as words per minute. Reading comprehension (Appendix C) was also measured with the accuracy of their responses to the content-relevant questions after each reading session.

2.5.3 Accommodative response during reading

The mean of real-time accommodative response (Figure 2) was calculated for that the subject had exerted at each 200 msec. Measurements were obtained using the automated autorefractor before and after the fatigue-inducing task.

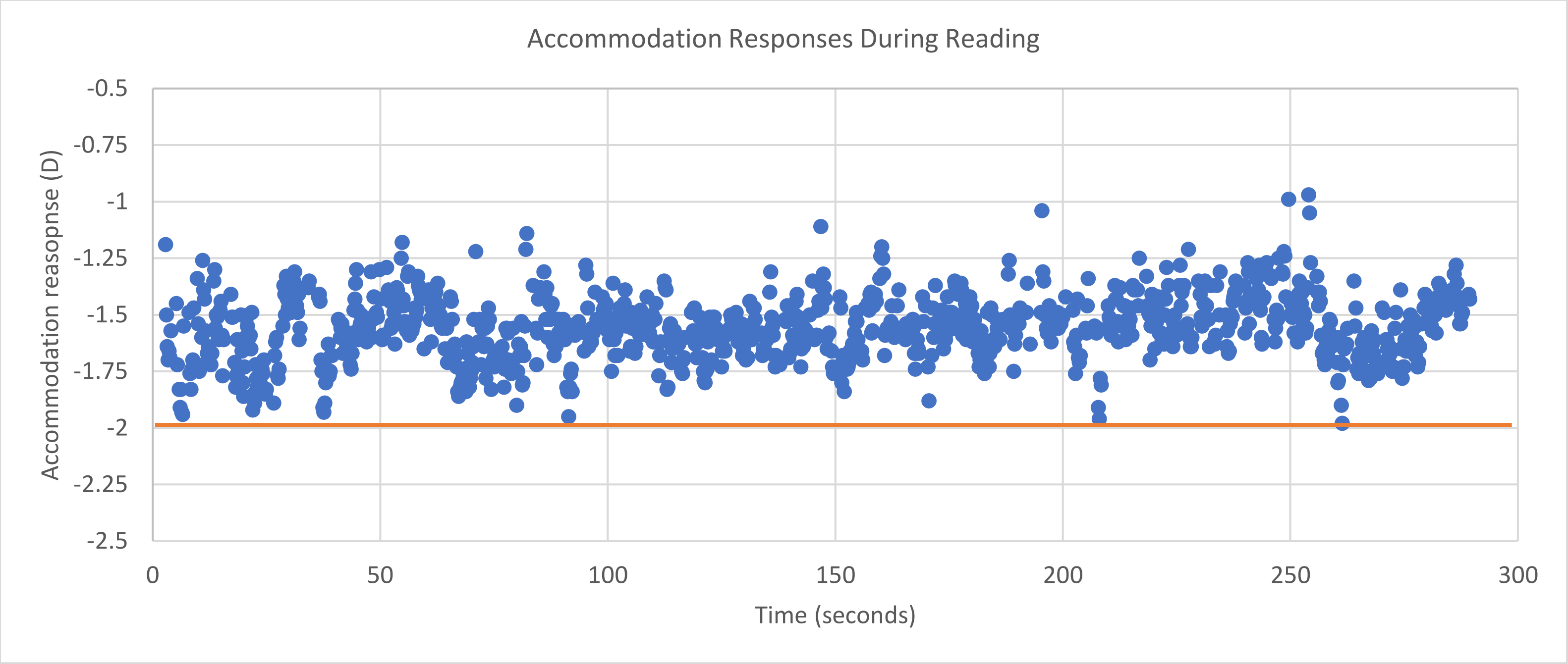


***Figure 2**. Accommodation responses during reading as a function of time. The orange line represents the accommodative demand for the reading test (-2D).*

2.5.4 Accommodative response stability during reading

An average of the standard deviations of the accommodative responses was calculated for each subject before and after the fatigue-inducing task using an automated autorefractor. (Figure 2)

2.5.5 Pupil size during reading

The average and standard deviation of pupil size measurements were obtained using the automated autorefractor while the subject was reading before and after the fatigue-inducing task. (Figure 3)

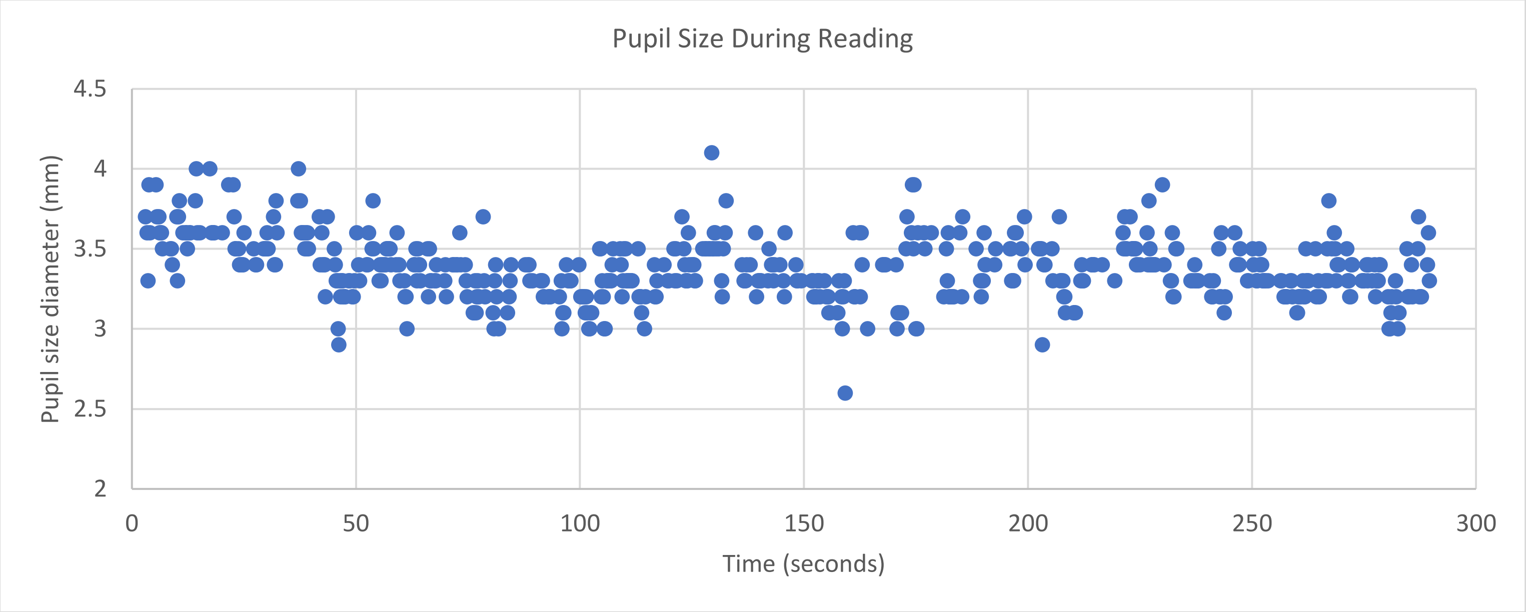


Figure 3. *Pupil size as a function of time during reading.*

2.5.6 Response time and Response accuracy at the facility test

Subjects were instructed to verify the orientation of the letter E by pressing on the corresponding arrow keys of a wireless keyboard every time a target was presented. Subjects' responses were recorded using our custom-made program. Correct responses indicated the subject's ability to resolve the presented target.

Recording the duration of how long it takes the subject to see and respond to the letter E orientation using our custom-made program provided the measure of accommodative latency.

2.5.7 Accommodative response accuracy during the facility test

For each distance (near=25 cm, far=500 cm), the mean of accommodative responses for each fixation was measured, then the mean of all fixations was calculated (Figure 4). This was measured before and after the fatigue-inducing task.

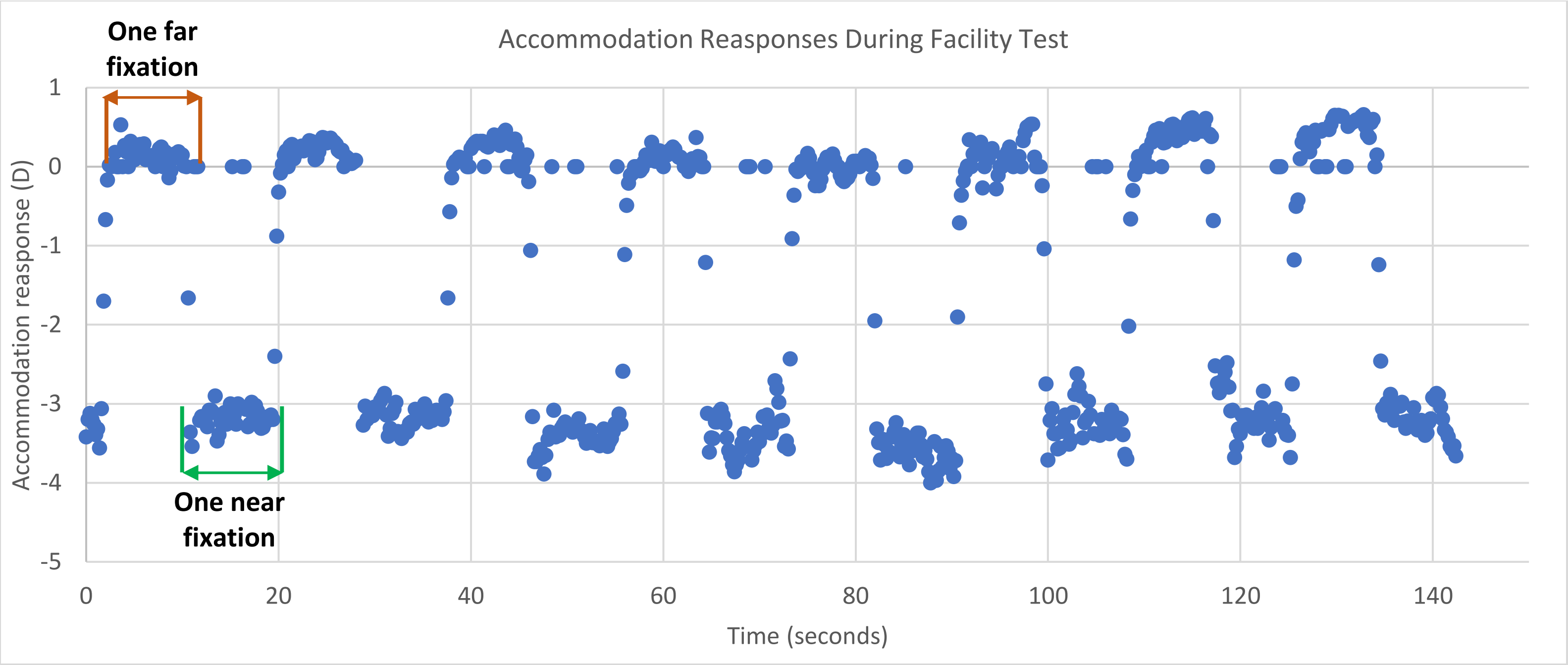


Figure 4. *Accommodation responses during facility test as a function of time. The orange arrows represent the beginning and the end of one far fixation (accommodative demand = -0.2 D). The green arrows represent the beginning and the end of one near fixation (accommodative demand = -4 D).*

2.5.8 Accommodative response variability during the facility test

For each distance (near=25 cm, far=500 cm), an average of the standard deviations of the accommodative responses for each fixation was measured, then the mean of all fixations was calculated (Figure 4). Measurements were obtained before and after the fatigue-inducing task.

2.5.9 Pupil size during the facility test

An average and standard deviation of pupil size measurements were recorded before and after the fatigue-inducing task at both distances using the automated autorefractor. (Figure 5)

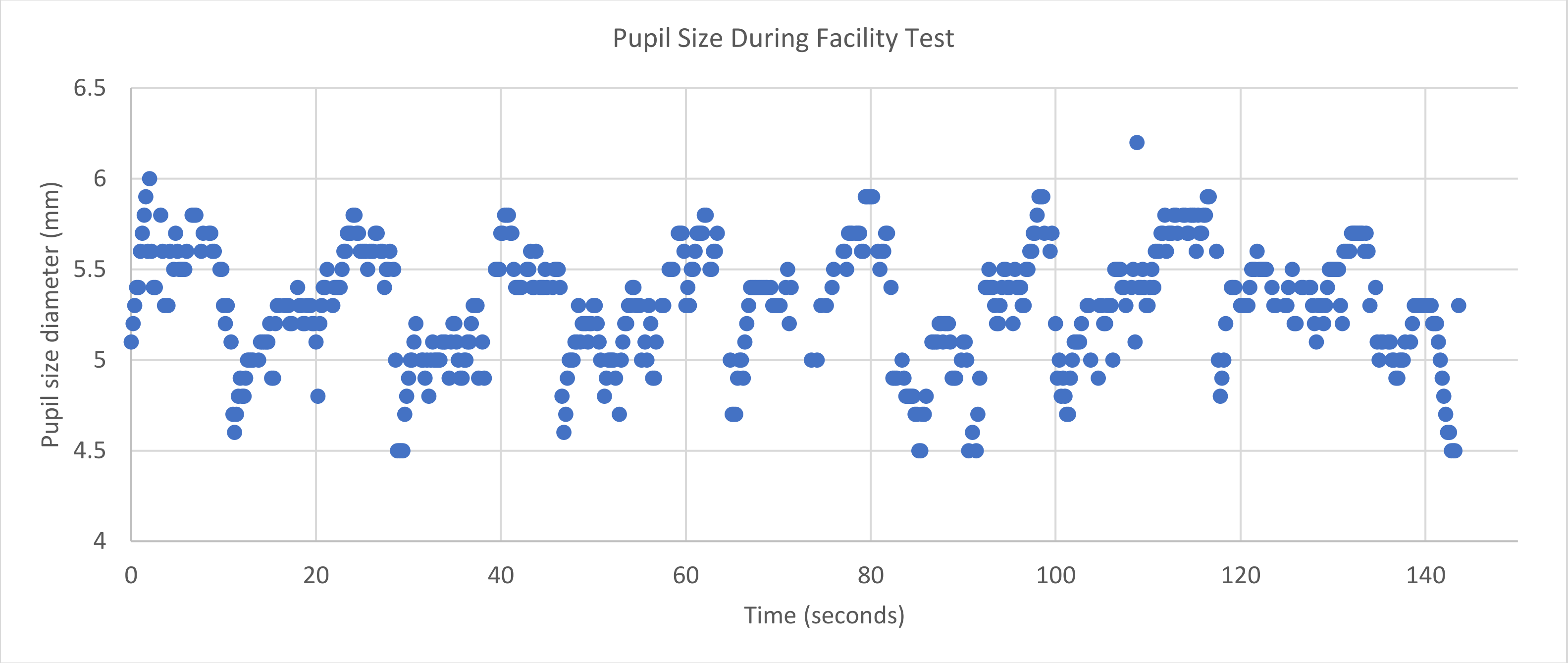


Figure 5. *Pupil size changes as a function of time during facility test.*

2.6 Data analysis

Data was coded with Microsoft Excel (Microsoft Corporation, Redmond, Wash) and then fed into IBM SPSS Statistics software v22.0 (Armonk, NY, USA) for statistical analysis. Mean, and standard deviation was obtained for the variables mentioned above (in section 2.5). Pairwise comparison was conducted first to compare the subject's subjective rating of visual discomfort, visual performance (RT and accuracy), and visual measurements (accommodative power and pupil size) before and after fatigue-inducing condition. Then Mixed-Model Analysis of Covariance (ANCOVA) was used to compare the effects of fatigue-inducing condition (Condition), symptomatic vs. asymptomatic group (Group), past-task order (Order) and their interactions on all target measurements with pre-test measurement as covariate. The effect size (Cohen's *d*) was calculated by taking the difference between two means, then dividing the outcome by the pooled standard deviation. Effect size values of d = 0.2, 0.5 and 0.8 correspond to small, medium and large effects, respectively although only values of ≥ 0.5 were reported.

The effect size of the main effect “Order” or its interactions was not calculated due to the unbalanced randomization of Orders among subjects.

3. Results

3.1 Categorization of the subject group: symptomatic vs. asymptomatic

Based on their CISS scores, subjects were categorized into two groups: symptomatic (6 subjects, mean score= 25.7, SD= 3.14) and asymptomatic (17 subjects, mean score= 12.8, SD= 4.17). For the symptomatic group, most of the subjects (five out of six) were females, in comparison to the about-equal gender distribution (female: male = 8: 6) in the asymptomatic group. This is consistent with a higher rate of females in the symptomatic group reported by Borsting et al. in a study with a sample size of 594 college students.[32]

3.2 Comparison of pre- and post-measurements

Comparing to the sum of subject's ratings on the 17 VDS items (the pre-VDS-total score), subjects' total rating of visual discomfort (post-VDS overall score) was increased significantly after the fatigue-inducing task ($\text{Mean}_{\text{pre-}}$= 8.2, $\text{Mean}_{\text{post}}$ = 12.3, (F (1, 90) = 20.719, $P < .0001$)) as illustrated in the bar chart below (Figure 6).

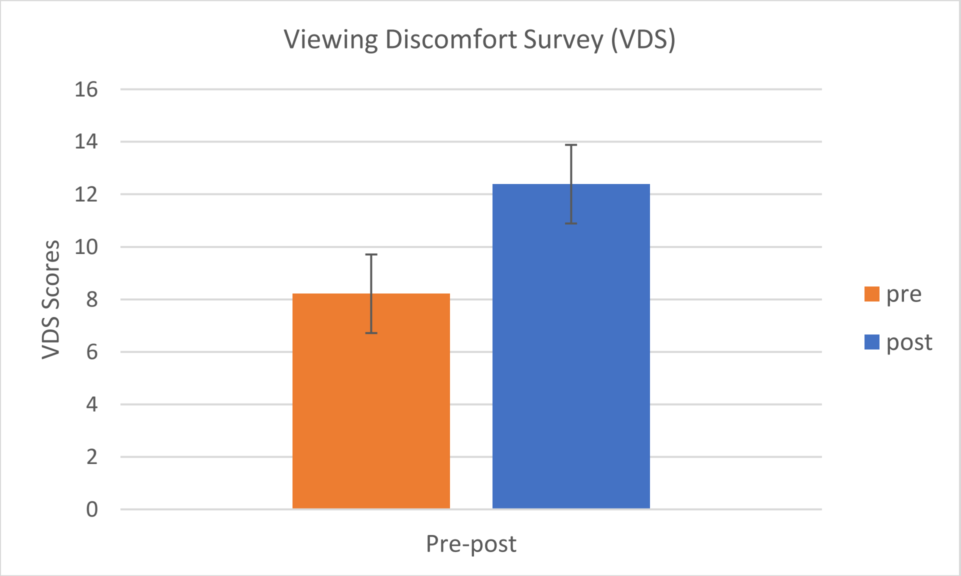


Figure 6. Means of the pre-VDS and post-VDS total scores with 84% confidence intervals (CI). The error bars show the 84% confidence interval. Non-overlapping error bars indicate a statistically significant difference between the corresponding measures at an alpha value of .05. The same interpretation is applied to the following figures.

A comparison of the average score of each question between pre- and post- symptom level is shown in (Figure 7). Subjects were also asked to rate two questions on a 5-points Likert scale after the pre- and post-reading test. One question was about the overall fatigue sensation, and the second was about the level of eye strain. Subjects reported higher symptoms after the fatigue-inducing task in both questions ($P < .0001$, $P < .0001$, respectively). Table 1 shows the means and p-values of the pre-and post-variables on VDS, reading, and the free-space facility test (near facility and far facility). Reading speed was increased after the fatigue-inducing task than before the task ($P < .0001$); however, reading comprehension was not changed ($P = .32$). In the facility test at both distances, neither response accuracy nor reaction time changed significantly after the fatigue-inducing task. Similarly, no significant difference was found before and after the fatigue-inducing task on the accommodative response and stability in reading and the facility test. Nonetheless, significant differences were found on the pupil parameters: with smaller ($P < .0001$) (Figure 8) and more variable ($P = .03$) pupil size in reading and also smaller pupil size in the facility test at near ($P = .001$) (Figure 9) and at far ($P = .001$) (Figure 10) distance though no difference was observed for its stability.

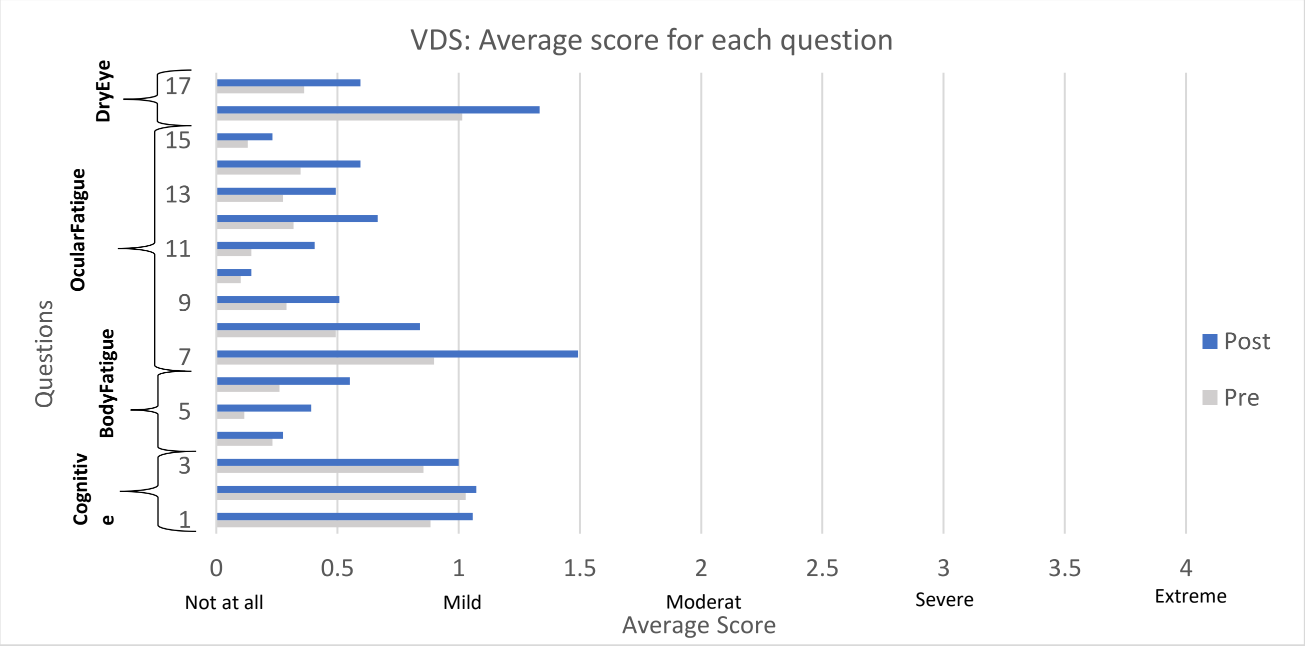


Figure 7. *Distribution of the percentages of pre-and post-symptoms level from "not at all" to "extremely" on VDS (Viewing discomfort survey).*

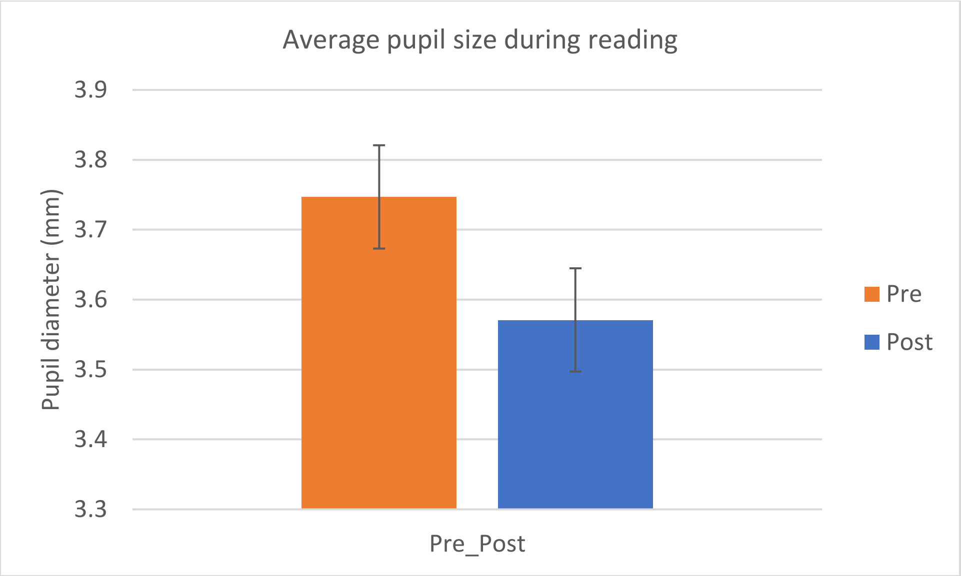


Figure 8. *Means of pre- and post-pupil size during the reading with 84% CI.*

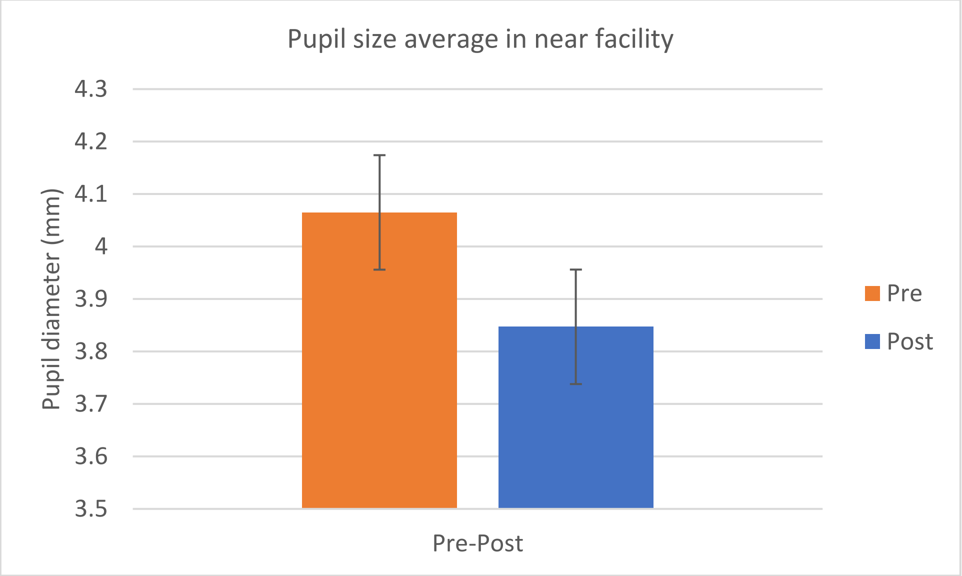


Figure 9. *Means of pre- and post-pupil size during the near facility with 84% CI.*

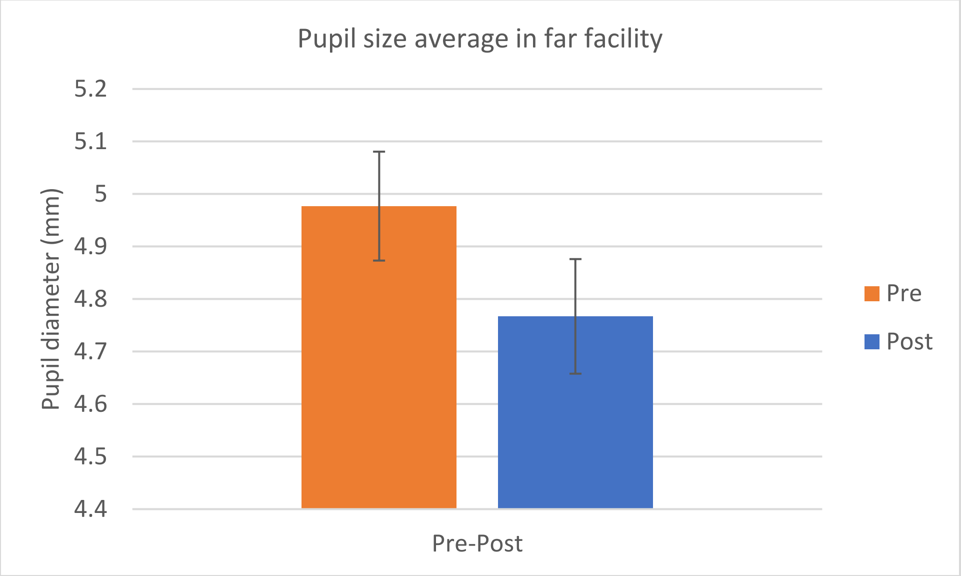


Figure 10. *Means of pre- and post-pupil size during the far facility with 84% CI.*

In sum, subjects reported more severe visual discomfort after the fatigue-inducing task along with changes on the pupil response. In the following analyses, we will use pre-task measurements as a covariate to compare the effects of different fatigue-inducing task conditions (Condition), subject group (Group), and post-task testing order (Order; when applicable) on the target measurements.

TABLE 1. *Means and P-values of the pre-post paired t-tests on reading and facility tests.*

Task	Variable	Mean Pre	Mean Post	Numerator df	Denominator df	F	Sig. (P value)
Reading	VDS total score	7.754	11.652	1	114.000	24.167	**.000**
	Q1: Overall fatigue	.406	1.275	1	114	76.425	**.000**
	Q2: Eye strain	.275	1.101	1	114.000	59.262	**.000**
	Reading speed (msec)	189.698	206.742	1	114.000	13.997	**.000**
	Comprehension rate (%)	.914	.955	1	86.712	1.012	.317
	Accommodative response accuracy (D)	-1.592	-1.621	1	114.000	.655	.420
	Accommodative stability (D)	.167	.179	1	114	1.499	.223
	Pupil size mean (mm)	3.747	3.571	1	114.000	17.990	**.000**

	Pupil size stability (mm)	.235	.252	1	114.000	4.691	**.032**
Far Facility	Response accuracy (%)	.993	.993	1	114.000	.000	1.000
	Reaction time (msec)	1899.745	1817.099	1	114.000	1.628	.205
	Accommodative response accuracy (D)	-.387	-.439	1	114.000	2.001	.160
	Accommodative stability (D)	.169	.175	1	114.000	.186	.667
	Pupil size mean (mm)	4.977	4.767	1	113.020	12.803	**.001**
	Pupil size stability (mm)	.243	.255	1	113.070	1.949	.165
Near Facility	Response accuracy (%)	.993	.998	1	114.000	1.457	.230
	Reaction time (msec)	1852.998	1880.326	1	114.000	.168	.683
	Accommodative response accuracy (D)	-3.524	-3.488	1	114.000	.580	.448
	Accommodative stability (D)	.223	.246	1	114.000	3.044	.084
	Pupil size mean (mm)	4.065	3.847	1	114.000	12.665	**.001**
	Pupil size stability (mm)	.205	.213	1	114	.717	.399

3.3 Effects of Condition and Group on the subjective rating of VDS

Two-way Mixed Model ANCOVA was used to compare each item score under different Conditions and between Groups with adjusting for the pre-score. Only two questions (Q7: tired eye, Q12: blurry near vision) and the total score showed a significant difference between Conditions. Table 2 presents the p-value for each item in the VDS. Subjects reported “eye tiredness or eye strain feeling” after the NB condition more significantly than after the NM condition (*P* = .005). Subjects also reported “blurred vision at near” after NB condition more significantly than FB (*P* = .04), and NM (*P* = .02). This finding suggests that sustained binocular near viewing causes more eye strain and blurred vision than the other two conditions and complaints of eye strain and blurred vision was mildest after sustained monocular near viewing. The overall VDS score was significantly different between conditions (F (2, 53.591) = 3.508, *P* = .04) (Figure 11). Pairwise comparisons showed that the NB condition resulted in a stronger sensation of fatigue than the NM condition (*P* = .04), and nearly-so with a marginal significance (*P* = .054) when compared to FB Condition. The symptomatic group reported higher symptom level for “blurred vision at far” than the asymptomatic group (F (1, 21.291) = 6.454, *P* = .02). However, there were no significant differences between symptomatic groups, conditions, or their interactions on the other items. The mean, minimum, maximum scores of all the questions before and after the fatigue-inducing task are presented (Appendix D & E).

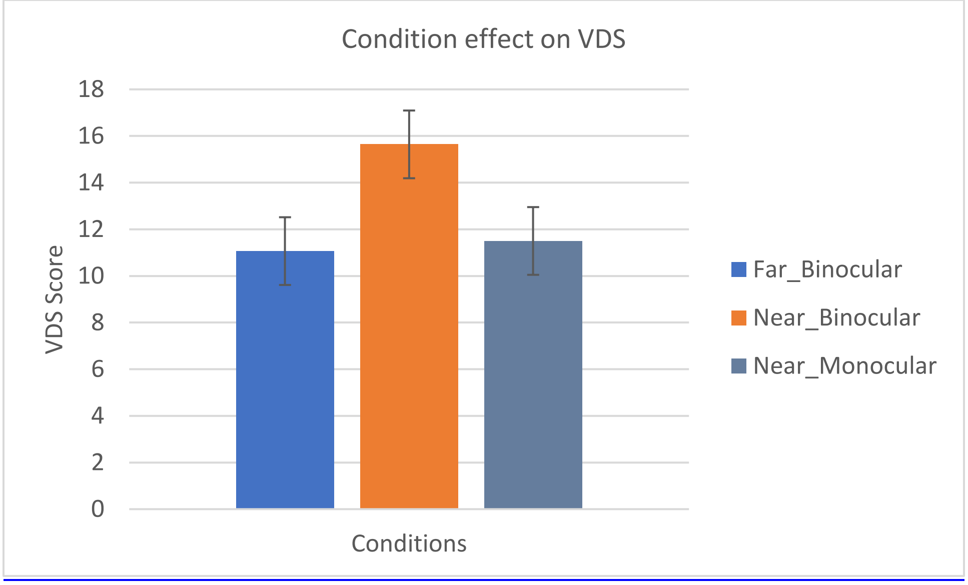


Figure 11. *Means of post-VDS scores between Conditions with 84% CI.*

TABLE 2. *Summary of Mixed Model ANCOVA of Fatigue-Inducing Condition on Visual Discomfort Symptoms on VDS.*

Category of symptoms	**Question number**	**The question**	**Numerator df**	**Denominator df**	**F value**	**P-value**
Cognitive symptoms	1	Did you have difficulty paying attention during the reading?	2	42.937	0.679	0.51
	2	Did you have trouble remembering what you just read?	2	41.545	0.941	0.39
	3	Did you feel like you have difficulty thinking clearly?	2	43.661	0.507	0.60
Body fatigue symptoms	4	Did you feel dizzy?	2	40.067	3.207	0.05
	5	Did you have a headache?	2	36.879	3.107	0.06
	6	Did you have body pain (e.g., pain in the neck, shoulder, or back)?	2	39.451	0.06	0.94
Eye fatigue symptoms	7	Did your eyes feel tired or strained?	2	42.151	4.46	**0.02**
	8	Did your eyes have a sensation of pulling?	2	34.765	1.818	0.18

	9	Did you feel pain inside your eyes?	2	39.168	0.451	0.64
	10	Did you feel sensitive to bright light?	2	42.254	0.765	0.47
	11	During the reading, did you feel the words moving or floating on the screen?	2	41.839	0.156	0.86
	12	Look at the near target (letter E), do you have blurry vision at near?	2	39.623	3.706	**0.03**
	13	Look at the near target, do you see two images (double vision) at near?	2	42.448	0.756	0.48
	14	Look at the far target (the page on the wall) do you have blurry vision at far?	2	43.55	1.23	0.30
	15	Look at the far target (the page on the wall), do you see two images (double vision) at far?	2	41.378	0.426	0.66
Dry eye symptoms	16	Did your eyes feel dry or watery?	2	42.9	0.493	0.61
	17	Did your eyes feel itchy, gritty, or sandy?	2	42.537	1.519	0.23
Total score			2	53.591	3.508	**0.04**

df: degree of freedom, VDS: viewing discomfort survey

We summed the symptoms scores of items underlying the same category for each subject, then we analyzed the ratings again. Among all four categories (cognitive, body, ocular, and dry eyes), only the dry eye symptoms were significantly different between Groups (F (1, 24.496) = 5.352, *P* = .03) with more severe dry eye for the symptomatic group. None of the other category scores were significantly different among conditions or between groups.

3.4 Effect of Condition, Group, and Order on reading measurements

Within-subject ANCOVA did not reveal any effect of Condition on the two questions (*P* = .5 for overall fatigue and *P* = .3 for eye strain) rated after the pre- and post-reading test. Reading speed was not significantly different among Conditions (F (2, 36.318) = 1.128, *P* = .34), between symptomatic Groups (F (1, 13.785) = .132, *P* = .72), or between post-task Orders (F (1, 51.263) = .471, *P* = .49). Descriptive statistics of the N, mean, and SD for all variables in the post tasks are shown in Table 3.

TABLE 3. Descriptive Statistics: N, Means, and SDs Averages for All Variables in Post Tasks for each Condition

Condition	Task	Variables	N	Mean	Std. Deviation
Far_Binocular	**Reading**	Accommodative Accuracy	23	-1.58	0.37
		Accommodative stability	23	0.18	0.09
		Pupil Size	23	3.59	0.54
		Pupil Size Stability	23	0.26	0.08
	Far Facility	Accommodative Accuracy	23	-0.45	0.68
		Accommodative stability	23	0.18	0.14
		Pupil Size	23	4.85	0.70
		Pupil Size Stability	23	0.26	0.07
		Response Accuracy	23	1.00	0.00
		Reaction time	23	1703.03	383.07
	Near Facility	Accommodative Accuracy	23	-3.49	0.53
		Accommodative stability	23	0.27	0.15
		Pupil Size	23	3.92	0.78
		Pupil Size Stability	23	0.23	0.11
		Response Accuracy	23	0.99	0.03
		Reaction time	23	1767.64	520.47
		Valid N (listwise)	23		
Near_Binocular	**Reading**	Accommodative Accuracy	23	-1.61	0.42
		Accommodative stability	23	0.18	0.08
		Pupil Size	23	3.57	0.68
		Pupil Size Stability	23	0.25	0.08
	Far Facility	Accommodative Accuracy	23	-0.44	0.59
		Accommodative stability	23	0.17	0.08
		Pupil Size	23	4.72	0.88
		Pupil Size Stability	23	0.25	0.08
		Response Accuracy	23	0.99	0.05
		Reaction time	23	1907.60	600.94
	Near Facility	Accommodative Accuracy	23	-3.44	0.53
		Accommodative stability	23	0.24	0.09
		Pupil Size	23	3.86	0.94
		Pupil Size Stability	23	0.21	0.09
		Response Accuracy	23	1.00	0.00
		Reaction time	23	2034.89	1016.61
		Valid N (listwise)	23		

Near_Monocular	**Reading**	Accommodative Accuracy	23	-1.67	0.46
		Accommodative stability	23	0.17	0.07
		Pupil Size	23	3.55	0.61
		Pupil Size Stability	23	0.24	0.07
	Far Facility	Accommodative Accuracy	23	-0.43	0.64
		Accommodative stability	23	0.17	0.07
		Pupil Size	23	4.71	0.66
		Pupil Size Stability	23	0.26	0.07
		Response Accuracy	23	0.99	0.04
		Reaction time	23	1840.67	630.98
	Near Facility	Accommodative Accuracy	23	-3.54	0.54
		Accommodative stability	23	0.22	0.06
		Pupil Size	23	3.75	0.64
		Pupil Size Stability	23	0.20	0.06
		Response Accuracy	23	1.00	0.00
		Reaction time	23	1838.45	518.96
		Valid N (listwise)	23		

During the reading test, the accommodative response did not show any significant difference among Conditions (F (2, 33.75) = 0.31, *P* = 0.73), between Groups (F (1, 12.54) = 0.51, *P* = 0.49), or between Orders (F (1, 55.16) = 2.64, *P* = 0.11). Similarly, the accommodative stability did not show any significant difference between Conditions (F (2, 38.07) = 0.31, *P* = 0.74), between Groups (F (1, 16.15) = 0.42, *P* = 0.53), or between Orders (F (1, 45.86) = 1.12, *P* = 0.3). However, significant interaction of Condition by Order was observed for accommodation stability (F (2, 49.74) = 3.90, *P* = 0.03). In the 2nd Order (Facility-Reading), higher instability was observed after the NB than after the NM Condition (*P* = .03). Also, under the NB Condition, accommodative instability was significantly higher during reading in the 2nd Order (Facility-Reading) than in the 1st Order (Reading-Facility) (*P* = .01). No effect of Groups was observed on accommodation stability (F (1, 16.15) = 0.42), P = .53).

For average pupil size, no difference was observed among Conditions (F (2, 31.05) = 0.327, *P* = .72) or between Orders (F (61.791, 3.416) P = 0.07). A significant effect was shown between Groups

(Group$_{sym=}$ 3.659, Groupa$_{sym}$= 3.537, (F (1, 44.439) = 9.28, *P* = .004)); however, statistics were not reported by SPSS, possibly due to the small sample size. For pupil size stability, no statistically significant effect was observed among Condition (F (2, 36.167) = 1.661, *P* = .20) though a clinically significant effect size (ES) was observed between FB and NM conditions (ES = .545). A statistical and clinically significant difference in pupil size stability was observed between Groups (*P* = .02, ES = -1.113), between Orders (*P* = .001) and with their interaction Group x Order (F (1, 52.466) = 4.029, *P* = 0.049). Pairwise comparisons showed that in the 2nd Order the pupil size of the symptomatic group was more unstable than that of the asymptomatic group (*P* = .007). Also, within the symptomatic group, pupil size during reading was more unstable in the 2nd Order than in the 1st Order (*P* = .005). Table 4 shows the measures of the effect size of the tested variables in the reading test.

TABLE 4. The effect size values of the reading test variables

Variables	Conditions			Groups
	FB-NM	**FB-NB**	**NM-NB**	**Asym - Sym**
Accommodative Response Accuracy	0.234	0.146	-0.087	-0.252
Accommodation Stability	0.034	-0.188	-0.222	-0.191
Pupil Size Mean	0.216	0.195	-0.022	-0.490
Pupil Size Stability	**0.545**	0.223	-0.322	**-1.113**

Asym: Asymptomatic Group, Sym: Symptomatic Group

3.5 Effect of Condition, Group, and Order on free-space facility measurements: Far distance

There was a significant difference among Conditions in the RT to the far target (FB= 1788.68 msec, NB= 2010.874 msec, NM= 1893.802 msec, (F (2, 28.502) = 4.403, *P* = 0.02)); however, no statistics to be reported due to small sample size. There was a significant difference between Orders (F (1, 38.353) = 4.716, *P* = 0.04). In the 2nd Order, when facility test was immediately following the fatigue-inducing condition, RT was significantly slower than the 1st Order (*P* = .04) where Facility test was tested after reading. There was no significant difference between Groups in RT at far (F (1, 6.455) = 2.141, *P* = 0.19). Also, there was a clinical significance between groups on RT (d = - 0.503).

There was also a significant difference between Conditions in response accuracy (F (2, 55.244) = 26.018, *P* < .0001). After FB, subjects were more accurate in their response to the target than after NM (*P* = .046). There was no significant difference in response accuracy between Orders (*P* = .06) or Groups (*P* = .30). However, there was a moderate to high clinical significance between FB and NM in the response accuracy (d = 603).

During the far fixation aspect of the facility test, the accommodative response did not show any significant difference between Conditions (F (2, 41.902) = 0.291, *P* = 0.74), between Groups (F (1, 17.993) = 1.284, *P* = 0.27), or between Orders (F (1, 55.16) = 2.64, *P* = 0.11). There was a significant effect of Conditions on accommodative stability with FB showing a significantly higher instability than both near conditions, NB (*P* = .03) and NM (*P* = .04). Further, Cohen's effect size value (d = 0.741) suggested a moderate to high clinical significance. There were no significant effects of Groups (*P* = .1) or Orders (*P* = .4) on accommodative stability. However, there was a clinical significance between groups on accommodative stability (d = - 0.662). There was a significant interaction between Conditions and Groups in the accommodative stability (F (2, 38.302) = 7.207, *P* = .002). Among the symptomatic group, accommodative instability after FB condition was significantly larger than after both near conditions, NB (*P* = .002) and NM (*P* = .003). After FB condition, the symptomatic group had more unstable accommodative response than the asymptomatic group (*P* = .001). Further, Cohen's effect size value (d = - 1.882) suggested a high clinical significance between Groups after FB condition.

The mean pupil size did not show any significant difference between Conditions (F (2, 42.214) = 2.353, *P* = 0.11), Orders (F (1, 44.772) = 2.631 *P* = 0.11), or Groups (F (1, 18.243) = 0.081, *P* = 0.78). Further, Cohen's effect size value (d = 0.633) suggested a moderate to high clinical significance between conditions on the pupil size mean. Pupil stability showed a statistically significant difference between Conditions (F (2, 41.703) = 3.958, *P* = 0.03) with FB condition showing more instability than NB (*P* = .04) and moderate to high clinical significance (d= 0.736). Also, there was a moderate to high clinical significance between FB and NM conditions on pupil stability (d = 667). There was a significant effect of the Order on pupil stability (F (1, 40.577) = 8.14, *P* = .007) with the 2nd Order showing more instability than the 1st Order (*P* = .007). Also, there was a statistically significant effect of Groups on pupil stability (F (1, 16.444) = 6.835, *P* = 0.02) with the symptomatic group manifesting more instability than the asymptomatic group (*P* = .02). Also, Cohen's effect size value (d = -1.062) suggested a high clinical significance between Groups on the pupil size stability. The pupil size stability had a significant interaction of Condition x Group (F (2, 35.649) = 4.225, *P* = 0.02). The symptomatic group had more instability in the pupil size after FB than the other two near conditions, NB (*P* = .02) and NM (*P* = 009). Also, Cohen's effect size value (d = -1.918) suggested a high clinical significance between Groups on the pupil size stability. After the FB condition, pupil size of the symptomatic group was more unstable than that of the asymptomatic group (*P* = .001). Significant interaction effect of Group x Order (F (1, 40.726) = 5.126, *P* = 0.03) was also observed on pupil instability. Among the symptomatic group, the 2nd Order showed more instability than the 1st Order (*P* = .008). Also, In the 2nd Order, the symptomatic group had more instability than the asymptomatic group (*P* = .006). Table 5 shows the measures of the effect size of the tested variables in the facility-far task.

TABLE 5. The effect size values of the far facility test variables.

Variables	Conditions			Groups	Condition*Group		
	FB-NM	**FB-NB**	**NM-NB**	**Asym - Sym**	**FB (asym-sym)**	**NB (asym-sym)**	**NM (asym-sym)**
Accommodative Response Accuracy	0.061	0.218	-0.157	0.374			
Accommodation Stability	**0.741**	0.78	0.039	**-0.662**	**-1.882**	0.000	-0.083
Pupil Size Mean	**0.633**	0.408	-0.225	-0.083			
Pupil Size Stability	**0.667**	**0.736**	0.069	**-1.062**	**-1.918**	-0.049	-0.428
Response Accuracy	**0.603**	0.352	-0.251	-0.379			
Reaction Time	-0.288	-0.608	-0.32	**-0.503**			

Asym: Asymptomatic Group, Sym: Symptomatic Group.

3.6 Effect of Condition, Group, and Order on free-space facility measurements: Near distance

There was a significant difference between Conditions (F (2, 50.139) = 6.9, *P* = .002) in the RT to the near target; however, the pairwise comparison did not show the tendency of the change due to the low number of variances. There was a significant clinical difference between NM and NB on RT (d = -0.515). There was a significant difference between Orders (F (1, 26.438) = 12.404, *P* = .002) on RT with slower RT in the 2nd Order than in the 1st Order (*P* = .002). Also, there was a statistically and clinically significant difference between Groups (F (1, 19.549) = 19.729, *P* < .0001, d = -1.159); the symptomatic group had a slower RT than the asymptomatic group (*P* < .0001). A significant interaction was found between Orders and Groups in the RT (F (1, 30.014) = 16.023, *P* < .0001). Among the symptomatic group, the RT in the 2nd Order was significantly slower than the RT in the 1st Order (*P* < .0001). Also, in the 2nd Order, the symptomatic group were slower in their RT than the asymptomatic group (P < .0001). There were no significant effects of Conditions (F (2, 44.736) = 1.138, *P* = 0.33), Orders (F (1, 41.74) = 1.645, *P* = 0.21), or Groups (F (1, 20.079) = 0.139, *P* = 0.71) on the response accuracy.

The accommodation response accuracy showed no significant change in accommodative response accuracy between Conditions (F (2, 36.736) = 0.208, *P* = 0.81), or between Groups (F (1, 16.06) = 0.153, *P* = 0.70). There was a significant difference between Orders (F (1, 48.879) = 9.132, *P* = .004); however, no statistics were reported by SPSS in the follow-up pairwise comparison, possibly due to the small sample size. There was a significant difference between Conditions with FB condition showing more accommodative instability than the other two near conditions, NB (*P* = .004) and NM (*P* = .001) (Figure 12). There was a high clinical significance between FB and NM conditions (d = -1.269) and between FB and NB conditions (d = 1.113) on the accommodation stability. Also, there was a significant difference between Groups (*P* = .04) with the symptomatic group manifesting more accommodative instability than the asymptomatic group and clinical significance (d = -0.827). The Order had a significant effect on accommodation stability at near fixation with the 2nd Order showing more accommodative instability than the 1st Order (F (1, 36.992) = 6.432, *P* = .02). There was a significant interaction between Groups and Conditions in the accommodation stability (F (2, 36.336) = 7.615, *P* = .002). Among the symptomatic group, accommodation was more unstable after the FB condition than the other two near conditions, NB (*P* = .001) and NM (*P* < .0001). After the FB condition, the symptomatic group had more accommodation instability than the asymptomatic group (*P* < .0001).

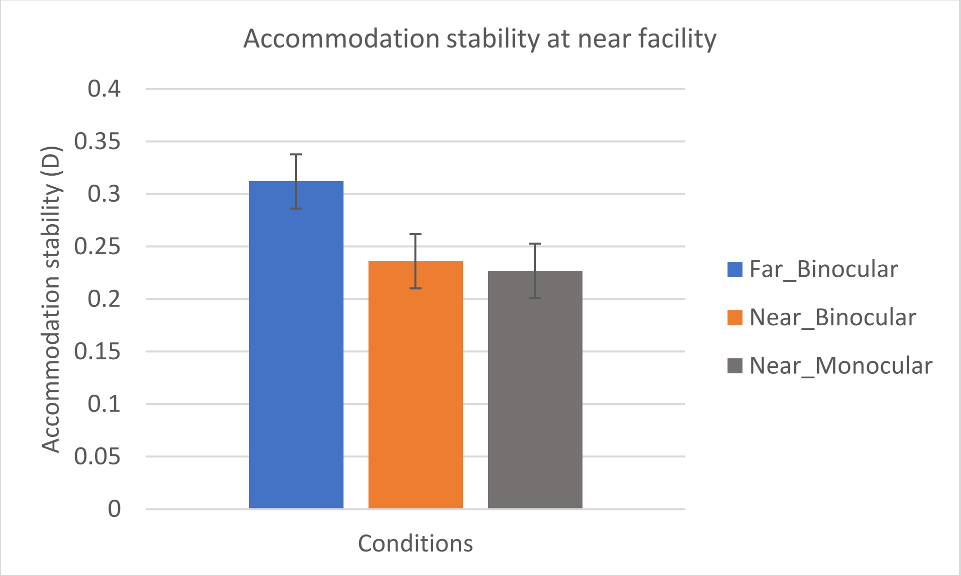


Figure 12. *Means of post-accommodative stability at the near facility between Conditions with 84% CI.*

The pupil size means only showed a significant difference between Conditions (F (2, 44.168) = 4.73, *P* = 0.01) in which the FB condition demonstrated larger pupil size during the near facility fixation than the other two near conditions, NB (*P* = .04) and NM (*P* = .006) (Figure 13). Further, Cohen's effect size value suggested a moderate to high clinical significance between FB and NM conditions (d = 0.869), and FB and NB conditions (d = 0.639) on pupil size mean. There was no significant difference between Orders (*P* = .13) or Groups (*P* = .36).

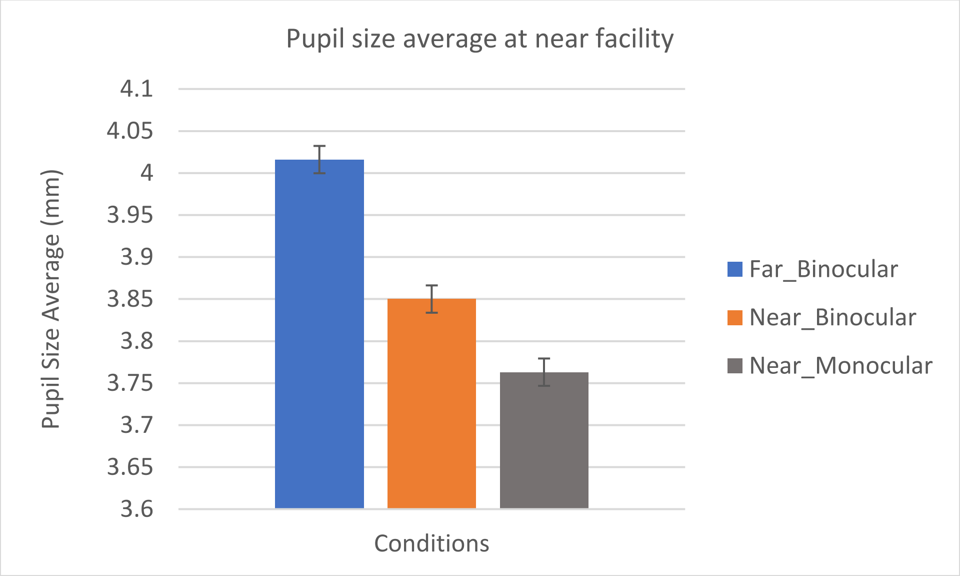


Figure 13. *Means of post-pupil size at the near facility between Conditions with 84% CI.*

The pupil stability showed a statistically and clinical significant difference between conditions (F (2, 38.652) = 4.028, *P* = 0.03) with the FB showing more pupil instability than the NM condition (*P* = .01, d = 0.972) (Figure 14). Also, there was a clinical significance between NM and NB conditions on more pupil stability (d = -0.691). There was a significant difference between Orders (F (1, 48.948) = 4.679, *P* = 0.04) with the 2nd Order showing more pupil instability than the 1st Order (*P* < .0001).

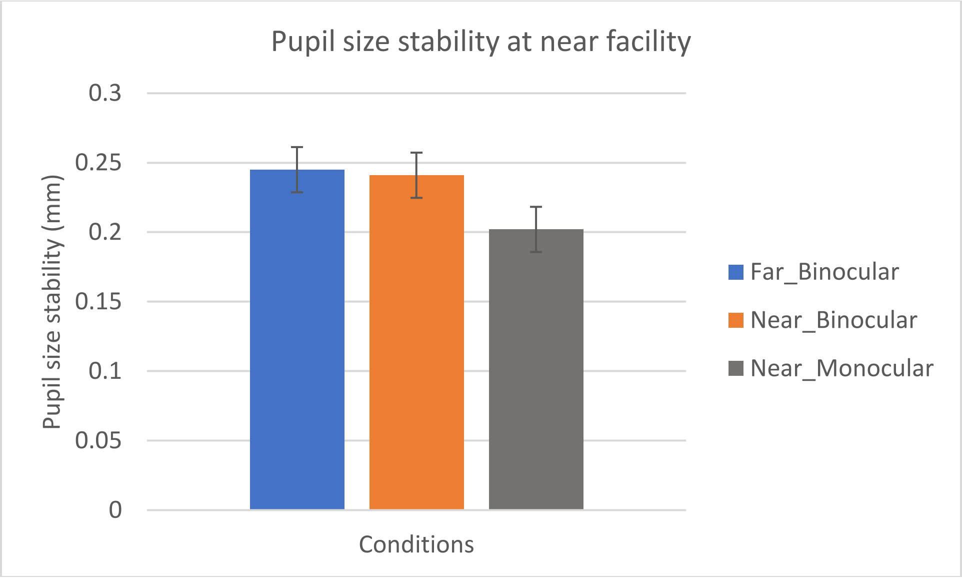


Figure 14. *Means of post-pupil size stability at the near facility between Conditions with 84% CI.*

Also, there was a statistically and clinical significant difference between Groups (F (1, 19.161) = 13.384, *P* = .002, d = -1.535) where the symptomatic group had more pupil instability than the asymptomatic group (*P* = .002). There was a significant interaction between Orders and Groups in pupil stability (F (1, 48.555) = 7.502, *P* = 0.009). Among the symptomatic group, the 2nd Order had more pupil instability than the 1st Order (*P* = .001). Also, in the 2nd Order, the symptomatic group had more pupil instability than the asymptomatic group (*P* < .0001). Table 5 shows the measures of the effect size of the tested variables in the facility-near task.

TABLE 6. The effect size values of the near facility test variables.

Variables	**Conditions**			**Groups**	**Condition*Group**		
	FB-NM	**FB-NB**	**NM-NB**	**Asym - Sym**	**FB (Asym-Sym)**	**NB (Asym-Sym)**	**NM (Asym-Sym)**
Accommodative Response Accuracy	0.176	0.009	-0.166	0.164			
Accommodation Stability	**1.269**	**1.113**	-0.155	**-0.827**	**-2.162**	-0.024	-0.033
Pupil Size Mean	**0.869**	**0.639**	-0.229	-0.313			
Pupil Size Stability	**0.972**	0.281	**-0.691**	**-1.535**			

Response Accuracy	-0.402	-0.402	0.000	-0.132			
Reaction Time	0.142	-0.373	**-0.515**	**-1.159**			

Asym: Asymptomatic Group, Sym: Symptomatic Group.

4. Discussion

4.1 The impact of the fatigue-inducing task on VDS and pupillary responses: Based on findings from comparisons of pre- and post-task measurements

4.1.1 A significant change on VDS rating but not reading performance

Our main hypothesis was that sustained near viewing of digital devices will stress the components of the near triad (accommodation, vergence, pupil size) and cause visual discomfort and deteriorated visual performance. The significant increase of the VDS total score and subjects' responses to the post-reading discomfort assessment (overall fatigue and eyestrain) after the fatigue-inducing task partially support our hypothesis that visual discomfort was increased after the fatigue-inducing task.

During the reading test, the post-Reading Speed (RS) increased significantly (RS_{pre}= 190 wpm vs. RS_{post}= 207 wpm) after the fatigue-inducing task without significant change in comprehension (pre-accuracy .91 vs. post-accuracy .95). The finding suggests no significant impact of the fatigue-inducing task on reading performance. Previous studies also found that reading performance is more subject to cognitive stress but relatively robust to the visual environment. It deteriorates only under extremely poor viewing conditions (e.g., text of extremely small font size, poor contrast, with crowded spacing, or under strong glare, etc.). The faster reading speed suggests that the fatigue-inducing task was not visually stressing enough to impact the reading performance; instead, the subjects likely habituated to the reading environment of the study setup and/or gained interest in the reading content.[43]

4.1.2 A significant change on pupillary responses but not on accommodation during post-task reading

No significant change of the accommodative parameters (the accommodative response accuracy and accommodation stability) was observed between pre- and post-task reading.

In comparison, significant changes were shown on both pupil size and pupil size stability. When reading after the fatigue-inducing task, pupil size became smaller and less stable than in the pre-task reading. The decrease in the pupil size association with severe fatigue symptoms was also observed in previous studies.[7,44] This may be explained by the concept that the neural signal for the accommodative change is expected to make a smaller or slower impact on the crystalline lens than that on the pupil diameter. There might also be a limitation of the current technology in the ability to detect subtle changes in the crystalline lens.

4.1.3 A significant change in pupil size but not on pupil stability, accommodation, and performance in post-task free-space facility

No significant differences were found on response accuracy and reaction time for the facility test before and after the fatigue-inducing condition, nor was any change observed on the accommodative response. Similar to the findings in the reading test; however, pupil diameter significantly decreased after the fatigue-inducing task for both far and near facility tests, although no difference was observed on pupil stability.

The pupil was significantly more constricted after the fatigue-inducing task than in the pre-task facility. The relationship between visual fatigue and pupil size has been investigated in previous studies in which they concluded that more severe fatigue symptoms led to more pupil constriction.[7,44] The observed pupil size constriction after near viewing might be attributed to the spasms of the sphincter pupillae and the ciliary muscles which both are innervated by the parasympathetic system.[7]

Further examination of the pupil size data and the accommodative instability in both tasks, we found a trend that larger pupil size seemed to be accompanied with more stable accommodative response whereas smaller pupil size seemed to be accompanied with higher accommodation instability. This is similar to what Charman and Heron observed from many studies. In a review paper on fluctuations in accommodation, they reported that larger pupil size accounts for more stable accommodation whereas smaller pupil size accounts for higher accommodation instability.[45]

4.2 Interpretation of the autonomic nervous system of the FB condition effect on accommodative and pupillary instability in facility

A significant difference of Condition was found on subjective rating of the total VDS score with higher rating after the NB condition than after NM. Consistently, when analyzing the individual survey questions, we found that “blurred vision at near” and “eye strain/tiredness” items were highly reported after NB than after the other two conditions. These findings suggest that when the vergence and the accommodation systems were involved as in the NB condition, the visual stress after sustained near work was intensified. No effect of Condition was found on all target measurement in reading.

Subjects’ behavior response to the far facility target was more accurate after the FB condition than after NM, which may indicate that the NM condition was more stressful and hence affected the performance afterward. On the contrary, no difference in response accuracy was found in the near facility test. While the far target orientation was randomized from trial to trial, the near target was a fixed letter. The predictability of the near target orientation explains the finding of no difference among Conditions at near facility.

The accommodative response (i.e., accuracy) showed no significant difference among conditions on both tasks. This may indicate that the fatigue-inducing task was not strong enough to cause changes in the accommodative response accuracy either in the reading test (which involves the adaptive component) or in the facility test (which involves the phasic component). However, accommodation instability was significantly higher at both distances of the facility test after FB condition than the other two near conditions.

During the near facility, pupil size was larger and more unstable after the FB than after NB and NM. The same trend was also observed in the far facility with pupil size more unstable after FB than after NB and NM. The same trend was observed on pupil diameter though the difference was not significant.

A potential reason for these findings is that during the FB condition (i.e., playing a game at a far distance for 25 min), the ratio of the sympathetic innervations to the parasympathetic is very high. Then upon moving to the post-facility test, the parasympathetic innervations were more engaged. This onset of parasympathetic activity working against the farpoint adapted state with relatively more sympathetic innervations may explain the accommodation instability measured at both distances of the facility test. Also, these findings suggest that continuous change of distance viewing (i.e., facility test, sinusoidal stimuli) may hinder the effort of the parasympathetic system in attaining accommodative accuracy, and the impact was even stronger after the minimal involvement of the parasympathetic state in far viewing (i.e., FB) than after sustained adaptation of the parasympathetic state in near viewing (i.e., NB and NM).

4.3 A poor dynamic accommodative function of the symptomatic group as revealed by higher pupil and accommodative instability at near facility test

No difference was found on subjective ratings of the overall VDS score and individual items between symptomatic and asymptomatic groups, except for the higher rating of “*blurred* vision at far” for the symptomatic group. As mentioned above, the finding of higher pupil instability after the FB condition may have resulted from tonus of the sphincter and ciliary muscles after the near work. The evaluation of the symptomatic group was according to their CISS scores, which suggests the existence of oculomotor dysfunction. Therefore, the higher pupil and accommodation instability at both near viewing tasks (reading and near facility) could reflect the effect of an oculomotor dysfunction at near on the accommodative and pupil stability performance. Also, it is worth noting that only “*blurred* vision at far” was significantly reported after the fatigue-inducing task rather than the “*double* vision at far.” Therefore, we suggest that the accommodative system is more likely to be affected by the sustained near viewing than the vergence system.

No difference in reading measurements was found between Groups. As subjects were categorized by their ratings on CISS, the group categorization does not warrant group difference on accommodative and pupil responses. As for the lack of group difference in reading speed and comprehension, it may be attributed to the display quality and short reading time. It has been frequently reported that symptomatic subjects tend to have more trouble in reading; however, in the current study the text was presented in proper font size, with wide line spacing, and narrow linewidth, which is easier to read, even for symptomatic subjects. The short reading time also lessens the possibility of finding a difference between groups.

In the near facility test, the reaction time of the symptomatic group was longer, and their accommodative instability was higher than those of the asymptomatic group. While the target blur was not an issue in the near facility (as the target orientation was known), it still took longer for the symptomatic subjects to move focus from far to near (accommodation) but not from near to far (de-accommodation). With sustained viewing, the adaptive element is activated, and the weakness of the oculomotor system was not readily to be manifested. However, activation and deactivation of the sympathetic and the parasympathetic systems when continuously changing viewing distances (i.e., in facility test) may exhaust the accommodative system, especially among symptomatic subjects.

4.4 The effect of the post-task order on reading and facility tests

The reaction time of the facility test at both near and far distances was significantly higher in the 2nd order where facility test immediately followed the fatigue-inducing task and more prominent among the symptomatic group. This indicates the immediate impact of the fatigue-inducing task on the facility performance. However, in the 1st order where facility test came after post-task reading, the effect of Condition on facility reaction time was not significant. Thus, we suggest that the reading test may reduce the effect of fatigue-inducing task.

There was no significant effect of the post-task order on accommodative response or the pupil diameter in reading and far facility; however, significant interaction of Group x Orders on pupil stability was shown in both tasks. In all tasks, the symptomatic group had higher pupil instability when tested with the 2nd order than when with the 1st order.

A significant interaction of Condition x Order was also observed on accommodative stability during reading. After the NB condition, higher accommodative instability in reading was observed under the 2nd order than under the 1st order. Significant effect of Order was observed at near facility with higher accommodative instability under the 2nd order. No Order effect was observed with far facility. Together, accommodative instability at near viewing (in both reading and near facility) was higher with the 2nd order than with the 1st order, suggesting that, under the 1st Order, the reading test that was administered first may reduce the effect of Condition and lessen the impact of it on the facility test (i.e., 1st order).

However, the post-task order was not equally randomized among subjects or between visits. Thus, it is worth noting that any significant differences we found between orders might not be reliable due to the small sample size in the symptomatic group, especially under Order 2. However, we reported our findings for its potential clinical implications and the considerable logic behind it.

4.5 Study design: The free-space facility test

One of the main contributions of the current study is the creation of the free-space facility program. As aforementioned, this program contains two phases. While the switching-focus phase permits measurement of accommodative speed, similar to a traditional accommodative facility test, it also allows a check of behavioral response accuracy once clarity is achieved, all with objective measurements to eliminate subjective errors. With a good sampling rate of continuous accommodative measurement, the program can also be used to track detailed difference between increasing and decreasing accommodative responses.

Furthermore, the added sustained-fixation phase yields measurements of accommodative precision and stability. According to Tosha et al., it requires 90 seconds or longer to detect the difference between symptomatic and asymptomatic group on accommodative lag in sustained viewing. By manipulating the fixating duration in the sustained-fixation phase, we will be able to test the adaptive accommodative response and compare it to the phasic accommodative response revealed in the switching-focus phase as in the accommodative facility test.

4.6 Limitations and other considerations

Our study limitations were the imbalanced randomization of the post-task order among subjects and the overall sample size. Future studies should Latin-square the order of the post-task order among subjects to obtain more satisfactory findings. Confined by the total testing time in each visit, the near-distance visual task used to induce visual fatigue was only 25 minutes, shorter than the typical duration continuously on digital devices in general. Therefore, the result may not reflect the full impact of near viewing on the accommodative system. Even though our fatigue-inducing task duration was relatively short, fatigue symptoms were apparent on pupil size mean, pupil stability and consequent changes in the accommodative system were observed. However, the findings were not consistent on all tasks or between factors. Thus, we think that longer duration of the fatigue-inducing task will certainly show more observations that provide a better understanding of the accommodation behavior under sustained near viewing situations. Due to these limitations and the other consideration, we caution our readers of generalizing our results.

5. Conclusion

5.1 Summary of results

Our findings showed that VDS total score increased significantly after the fatigue-inducing task, which partially supports our hypothesis in which sustained near viewing of digital devices will cause visual discomfort.

There was a significant decrease in the pupil size and more instability in its diameter after the fatigue-inducing task in both tests (reading and facility). Our finding was consistent with other findings that found that higher discomfort level is correlated with more pupil constriction. This may be explained by the concept that the neural signal for the accommodative variation is expected to make a minor or slower impact on the crystalline lens than that on the pupil diameter. A limitation of the current equipment to detect the changes in the crystalline lens may also explain the relative lack of accommodative changes in post-task testing.

When comparing between Conditions, VDS total rating was significantly higher after NB than NM, which indicates that when both systems (accommodation and vergence) were involved, the subject was more likely to report fatigue symptoms. After the FB condition, when performing the facility test, subjects had a significant accommodation instability. This instability may be explained by the low parasympathetic state of accommodative adaptation and the burst parasympathetic innervation required to achieve clarity of the near target.

The symptomatic group was categorized based on their CISS scores, which suggests the presence of oculomotor dysfunction. This group showed more pupillary and accommodative instability than the asymptomatic group at both near viewing tasks (reading and near facility), which may reflect the effect of an oculomotor dysfunction at near on the accommodative and pupil stability performance.

Accommodative instability at near viewing (in both reading and near facility) was higher with the 2nd order than with the 1st order. This finding suggests that the reading test might reduce the effect of Condition and reduce its impact on the facility test.

One of the contributions of the study is the implementation of a custom-made program to the testing procedure allowing for more accurate tracking of the subject's reaction time and response accuracy.

5.2 Clinical implications and recommendations

The order of the routine clinical exams may impact the results of some tests such as measuring the accommodative lag using MEM after facility test, especially among symptomatic subjects. Based on our findings, such an order may lead to some variations when measuring the lag. Another clinical consideration is that when a patient complains of fatigue while performing near tasks; however, the clinical tests do not show any problem. A clinician should consider that these symptoms may only be objectively detected while performing the near work, but after a task pause, may be hard to measure, although the fatigue symptoms might remain. Therefore, it is recommended to implement clinical tests to assess the oculomotor function while performing a near task for more appropriate treatment. The free-space facility program allows for controlling patients' responses and enables objective recordings of the reaction time and response accuracy. Thus, we suggest conducting further studies on the program and modify it to include a near computerized target (e.g. Heads-up display), extend the period of near fixation to test the adaptive component behavior during the facility test and to set new norms based on this method. Also, repetitive stimuli may impact the subject's accommodative response, reaction time and accuracy because of the predictive element; therefore, the program may provide a proper manipulation that helps in further understanding the accommodation behavior when using predicted and unpredicted stimuli.[46]

Lastly, there is a need to construct and validate a survey more designed to help identify patients who are symptomatic due to accommodative dysfunctions. Such a survey will help in identifying the symptoms types, the appropriate possible treatment and track improvements appropriately.

References

1. Rosenfield M. Computer vision syndrome: a review of ocular causes and potential treatments. Ophthalmic and Physiological Optics. 2011;31(5):502-515. doi:10.1111/j.1475-1313.2011.00834.x

2. Digital 2019: Global Internet Use Accelerates. We Are Social. https://wearesocial.com/blog/2019/01/digital-2019-global-internet-use-accelerates. Published January 30, 2019. Accessed July 14, 2019.

3. Thomson WD. Eye problems and visual display terminals--the facts and the fallacies. Ophthalmic Physiol Opt. 1998;18(2):111-119.

4. Sánchez-Román FR, Pérez-Lucio C, Juárez-Ruíz C, Vélez-Zamora NM, Jiménez-Villarruel M. Risk factors for asthenopia among computer terminal operators. Salud Publica Mex. 1996;38(3):189-196.

5. Dain SJ, McCarthy AK, Chan-Ling T. Symptoms in VDU operators. Am J Optom Physiol Opt. 1988;65(3):162-167.

6. Rossignol AMS, Morse EP, Summers VMM, Pagnotto LDC. Video Display Terminal Use and Reported Health Symptoms Among Massachusetts Clerical Workers. J Occup Med. 1987;29(2):112-118.

7. Saito S, Sotoyama M, Saito S, Taptagaporn S. Physiological Indices of Visual Fatigue due to VDT Operation: Pupillary Reflexes and Accommodative Responses. Industrial Health. 1994;32(2):57-66. doi:10.2486/indhealth.32.57

8. Moulakaki AI, Recchioni A, Águila-Carrasco AJD, Esteve-Taboada JJ, Montés-Micó R. Assessing the accommodation response after near visual tasks using different handheld electronic devices. Arq Bras Oftalmol. 2017;80(1):9-13. doi:10.5935/0004-2749.20170004

9. Glasser A, Vilupuru AS, Kasthurirangan S. Dynamics of Accommodative Fatigue in Rhesus Monkeys and Humans. Invest Ophthalmol Vis Sci. 2002;43(13):2014-2014.

10. Tosha C, Borsting E, Ridder III WH, Chase C. Accommodation response and visual discomfort. Ophthalmic and Physiological Optics. 2009;29(6):625-633. doi:10.1111/j.1475-1313.2009.00687.x

11. Thiagarajan P, Ciuffreda KJ. Visual Fatigue and Accommodative Dynamics in Asymptomatic Individuals. Optometry and Vision Science. 2013;90(1):57. doi:10.1097/OPX.0b013e31827a233e

12. Wolska A, Switula M. Luminance of the surround and visual fatigue of VDT operators. Int J Occup Saf Ergon. 1999;5(4):553-581. doi:10.1080/10803548.1999.11076438

13. Scheiman M, Wick B. Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders. Lippincott Williams & Wilkins; 2008.

14. Computer Vision Syndrome. https://www.aoa.org/patients-and-public/caring-for-your-vision/protecting-your-vision/computer-vision-syndrome. Accessed July 15, 2019.

15. Simmers AJ, Gray LS, Wilkins AJ. The influence of tinted lenses upon ocular accommodation. Vision Research. 2001;41(9):1229-1238. doi:10.1016/S0042-6989(00)00291-1

16. Liu C. Visual discomfort symptomology and its correlation with clinical measures of accommodative and vergence function. https://www.aaopt.org/detail/knowledge-base-article/visual-discomfort-symptomology-and-its-correlation-clinical-measures-accommodative-and-vergence. Published 2012. Accessed April 23, 2019.

17. Burns D, Evans B, Allen P. Clinical Measurement of Amplitude of Accommodation: A Review. Vol 15.; 2014.

18. Ciuffreda KJ. Accommodation, the pupil and presbyopia. Borish's Clinical Refraction. 1998:77-120.

19. Moodley VR. Amplitude, facility and accuracy of accommodation in a primary school population. African Vision and Eye Health. 2008;68(4):147-154. doi:10.4102/aveh.v68i4.196

20. Sterner B 1959-. Ocular accomodation. Studies of amplitude, insufficiency, and facility training in young school children.; 2004. https://gupea.ub.gu.se/handle/2077/16186. Accessed January 26, 2019.

21. Hung GK, Ciuffreda KJ, Rosenfield M. Proximal contribution to a linear static model of accommodation and vergence. Ophthalmic and Physiological Optics. 1996;16(1):31-41. doi:10.1046/j.1475-1313.1996.95001107.x

22. Hung GK, Ciuffreda KJ. Sensitivity analysis of relative accommodation and vergence. IEEE Transactions on Biomedical Engineering. 1994;41(3):241-248. doi:10.1109/10.284942

23. Hung GK, Ciuffreda KJ. Dual-mode behaviour in the human accommodation system. Ophthalmic and Physiological Optics. 1988;8(3):327-332. doi:10.1111/j.1475-1313.1988.tb01062.x

24. Hung GK, Semmlow JL. Static Behavior of Accommodation and Vergence: Computer Simulation of an Interactive Dual-Feedback System. IEEE Transactions on Biomedical Engineering. 1980;BME-27(8):439-447. doi:10.1109/TBME.1980.326752

25. Hung GK, Ciuffreda KJ, Khosroyani M, Jiang B-C. Models of Accommodation. In: Hung GK, Ciuffreda KJ, eds. Models of the Visual System. Topics in Biomedical Engineering International Book Series. Boston, MA: Springer US; 2002:287-339. doi:10.1007/978-1-4757-5865-8_8

26. Jiang BC. Accommodative vergence is driven by the phasic component of the accommodative controller. Vision Research. 1996;36(1):97-102. doi:10.1016/0042-6989(95)00051-Z

27. Rosenfield M, Ciuffreda KJ, Gilmartin B. Factors influencing accommodative adaptation. Optom Vis Sci. 1992;69(4):270-275.

28. Wong A. Eye Movement Disorders. Oxford University Press, USA; 2008. https://books.google.com/books?id=-5NsAAAAMAAJ.

29. Culhane HM, Winn B, Gilmartin B. Human dynamic closed-loop accommodation augmented by sympathetic inhibition. Invest Ophthalmol Vis Sci. 1999;40(6):1137-1143.

30. Gilmartin B. A review of the role of sympathetic innervation of the ciliary muscle in ocular accommodation. Ophthalmic Physiol Opt. 1986;6(1):23-37.

31. Wang Y, Zhong X, Zhang Y, et al. Visual fatigue following long-term visual display terminal work under different light sources. Lighting Research & Technology. 2017;49(8):1034-1051. doi:10.1177/1477153516677559

32. Borsting E, Chase CH, Ridder WH. Measuring visual discomfort in college students. Optom Vis Sci. 2007;84(8):745-751. doi:10.1097/OPX.0b013e31812f5f51

33. Ciuffreda KJ, Scheiman M, Ong E, Rosenfield M, Solan HA. Irlen lenses do not improve accommodative accuracy at near. Optom Vis Sci. 1997;74(5):298-302.

34. Rosenfield M, Gurevich R, Wickware E, Lay M. Computer Vision Syndrome: Accommodative and Vergence Facility. Invest Ophthalmol Vis Sci. 2009;50(13):5332-5332.

35. Anderson HA, Stuebing KK. Subjective vs Objective Accommodative Amplitude: Preschool to Presbyopia. Optom Vis Sci. 2014;91(11):1290-1301. doi:10.1097/OPX.0000000000000402

36. Chen AM, Borsting EJ, Lam D, Antonino A. Accommodative facility measured by +/-2.00 flipper and dioptrically equivalent target distances in adults with and without accommodative infacility. In: ; 2012.

37. Hoffman DM, Girshick AR, Akeley K, Banks MS. Vergence–accommodation conflicts hinder visual performance and cause visual fatigue. Journal of Vision. 2008;8(3):33-33. doi:10.1167/8.3.33

38. Rouse MW, Borsting EJ, Mitchell GL, et al. Validity and reliability of the revised convergence insufficiency symptom survey in adults. Ophthalmic Physiol Opt. 2004;24(5):384-390. doi:10.1111/j.1475-1313.2004.00202.x

39. Sheedy JE, Hayes JN, Engle J. Is all asthenopia the same? Optom Vis Sci. 2003;80(11):732-739.

40. Shasteen, Kulp MT, Mitchell GL. Test-retest reliability of the convergence insufficiency symptom survey in individuals with accommodative insufficiency. In: ; 2012.

41. Mitchell, Kulp MT. Symptom level of children with accommodative insufficiency.

42. Kundart J, Tai Y-C, Hayes J, Gietzen J, Sheedy J. Real-Time Objective Measurement of Accommodation While Reading. VPI Research. January 2010. https://commons.pacificu.edu/verg/4.

43. Bell T. Extensive Reading: Speed and Comprehension. Reading Matrix: An International Online Journal, 2001. https://eric.ed.gov/?id=EJ629602. Accessed August 18, 2019.

44. Ukai K, Howarth PA. Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations. Displays. 2008;29(2):106-116. doi:10.1016/j.displa.2007.09.004

45. Charman WN, Heron G. Fluctuations in accommodation: a review. Ophthalmic and Physiological Optics. 1988;8(2):153-164. doi:10.1111/j.1475-1313.1988.tb01031.x

46. Khosroyani M, Hung GK. A dual-mode dynamic model of the human accommodation system. Bulletin of Mathematical Biology; New York. 2002;64(2):285-299. doi:http://dx.doi.org.proxy.lib.pacificu.edu:2048/10.1006/bulm.2001.0274

Appendices

Appendix A: Viewing Discomfort Survey (VDS)

Instruction

Please answer the following questions based on your discomfort level.

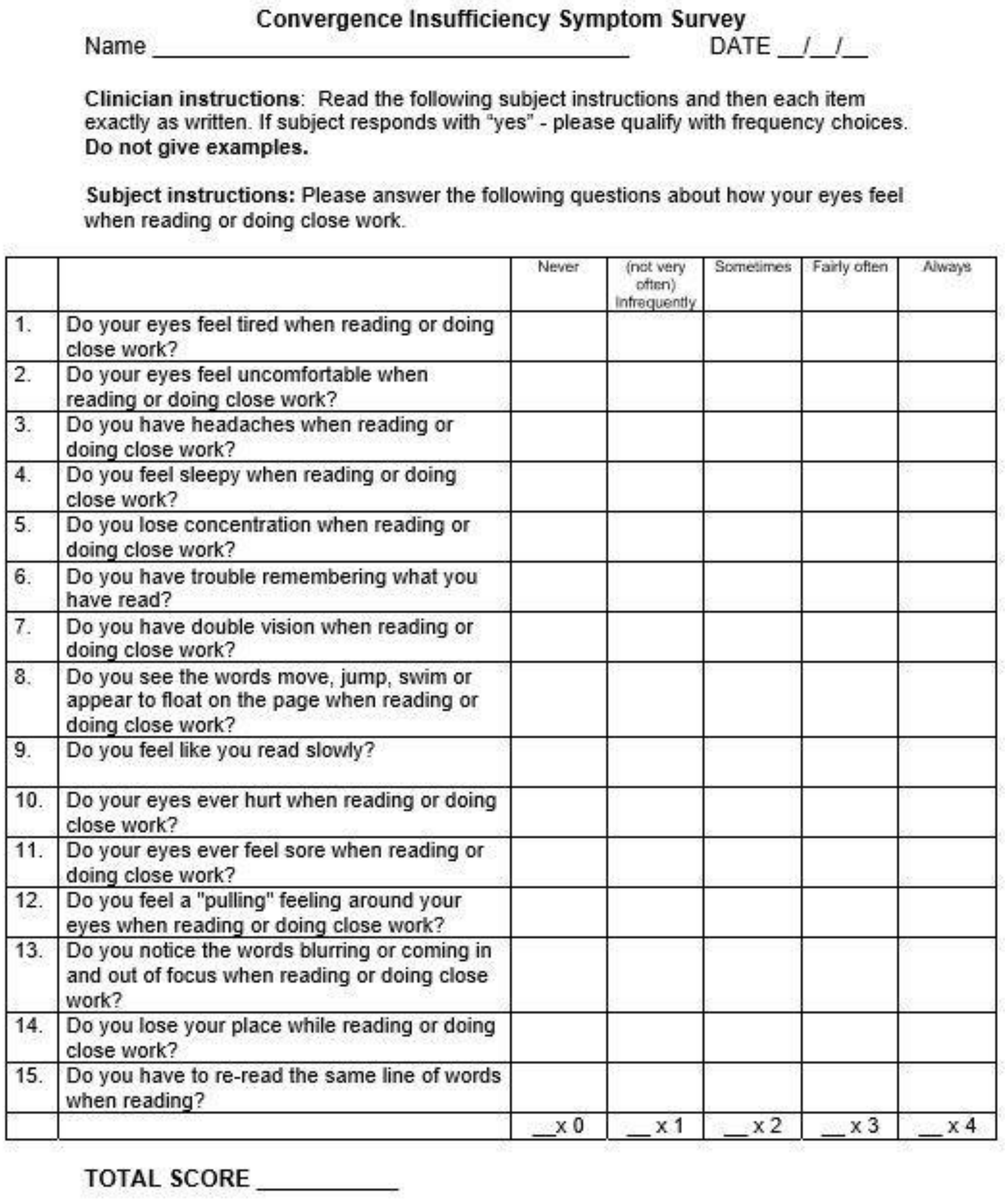
0 – Completely comfortable
1 – mildly discomfort
2 – Moderately discomfort
3 – Severely discomfort
4 – Extremely discomfort

A. Questions

Please answer the following questions based on how you felt when you were performing the previous tasks.

1. Did you have difficulty paying attention during the reading?
2. Did you have trouble remembering what you just read?
3. Did you feel like you have difficulty thinking clearly?
4. Did you feel dizzy?
5. Did you have headache?
6. Did you have body pain (e.g., pain in the neck, shoulder, or back)?
7. Did your eyes feel tired or strained?
8. Did your eyes have a sensation of pulling?
9. Did you feel pain inside your eyes?
10. Did your eyes feel dry or watery?
11. Did your eyes feel itchy, gritty or sandy?
12. Did you feel sensitive to bright light?
13. During reading, did you feel the words moving or floating on the screen?
14. Look at the near target (letter E), do you have blurry vision at near?
15. Look at the near target, do you see two images (double vision) at near?
16. Look at the far target (the page on the wall) do you have blurry vision at far?
17. Look at the far target (the page on the wall), do you see two images (double vision) at far?

Appendix B: Convergence Insufficiency Symptom Survey (CISS)



Convergence Insufficiency Symptom Survey

Name ______________________________________ DATE __/__/__

Clinician instructions: Read the following subject instructions and then each item exactly as written. If subject responds with "yes" - please qualify with frequency choices. **Do not give examples.**

Subject instructions: Please answer the following questions about how your eyes feel when reading or doing close work.

		Never	(not very often) Infrequently	Sometimes	Fairly often	Always
1.	Do your eyes feel tired when reading or doing close work?					
2.	Do your eyes feel uncomfortable when reading or doing close work?					
3.	Do you have headaches when reading or doing close work?					
4.	Do you feel sleepy when reading or doing close work?					
5.	Do you lose concentration when reading or doing close work?					
6.	Do you have trouble remembering what you have read?					
7.	Do you have double vision when reading or doing close work?					
8.	Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?					
9.	Do you feel like you read slowly?					
10.	Do your eyes ever hurt when reading or doing close work?					
11.	Do your eyes ever feel sore when reading or doing close work?					
12.	Do you feel a "pulling" feeling around your eyes when reading or doing close work?					
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?					
14.	Do you lose your place while reading or doing close work?					
15.	Do you have to re-read the same line of words when reading?					
		__x 0	__x 1	__x 2	__x 3	__x 4

TOTAL SCORE ___________

Appendix C: Reading comprehension questions

Page 3. The narrator wrote the story in

- 1700
- **1800**
- 1900

Page 10. What went missing in the narrator's/ writer aunt's house?

- **Diamond**
- Pen
- Indian vase

Page 24. How many Miss Herncastles are there?

- **Three**
- Two
- Four

Page 43. How did he describe his relationship with his wife?

- Happy couple
- Miserable couple
- **Not this or that**

Page 45/46. The narrator's daughter name is

- **Penelope**
- Selina
- Rachel

Page 48/51. The lady gave him a waistcoat made of

- Silk
- **Wool**
- Cotton

Page 65. Franklin Blake is coming back from his visit to his father in

- Frankfurt
- **London**
- Paris

Page 76. Who brought the diamond to the house?

- Mrs. Franklin
- The lady
- **Mr. Franklin**

Page 86. While he's out at the terrace, he found … Indians standing there?

- 4
- 5

- **3**

Page 99. the Indian poured something from the bottle, what is the color of it?

- **Black**
- Red
- Yellow

Page 121/132. Rosanna Spearman was the first house-made?
- True
- **False**

Appendix D: Descriptive statistics: pre-VDS questions

Questions (Pre)	N	Minimum	Maximum	Mean	Std. Deviation
PreQ1: Did you have difficulty paying attention during the reading?	69	0	3	.88	.738
PreQ2: Did you have trouble remembering what you just read?	69	0	4	1.03	.923
PreQ3:Did you feel like you have difficulty thinking clearly?	69	0	4	.86	.896
PreQ4:Did you feel dizzy?	69	0	3	.23	.598
PreQ5:Did you have headache?	69	0	1	.12	.323
PreQ6:Did you have body pain (e.g., pain in the neck, shoulder, or back)?	69	0	1	.26	.442
PreQ7:Did your eyes feel tired or strained?	69	0	3	.90	.689
PreQ8:Did your eyes have a sensation of pulling?	69	0	2	.49	.656
PreQ9:Did you feel pain inside your eyes?	69	0	2	.29	.517
PreQ10:Did your eyes feel dry or watery?	69	0	4	1.01	.831
PreQ11:Did your eyes feel itchy, gritty or sandy?	69	0	3	.36	.618
PreQ12:Did you feel sensitive to bright light?	69	0	2	.10	.349
PreQ13:During reading, did you feel the words moving or floating on the screen?	69	0	2	.14	.394
PreQ14:Look at the near target (letter E), do you have blurry vision at near?	69	0	2	.32	.556
PreQ15:Look at the near target, do you see two images (double vision) at near?	69	0	4	.28	.745

PreQ16:Look at the far target (the page on the wall) do you have blurry vision at far?	69	0	2	.35	.590
PreQ17:Look at the far target (the page on the wall), do you see two images (double vision) at far?	69	0	3	.13	.512
PreTotal	69	1	24	**7.75**	4.651

Appendix E: Descriptive statistics: post-VDS questions

Descriptive Statistics

Questions (Post)	N	Minimum	Maximum	Mean	Std. Deviation
PostQ1: Did you have difficulty paying attention during the reading?	69	0	3	1.06	.856
PostQ2: Did you have trouble remembering what you just read?	69	0	3	1.07	.896
PostQ3:Did you feel like you have difficulty thinking clearly?	69	0	3	1.00	.857
PostQ4:Did you feel dizzy?	69	0	3	.28	.591
PostQ5:Did you have headache?	69	0	2	.39	.647
PostQ6:Did you have body pain (e.g., pain in the neck, shoulder, or back)?	69	0	2	.55	.738
PostQ7:Did your eyes feel tired or strained?	69	0	4	1.49	.964
PostQ8:Did your eyes have a sensation of pulling?	69	0	4	.84	1.066
PostQ9:Did you feel pain inside your eyes?	69	0	2	.51	.760
PostQ10:Did your eyes feel dry or watery?	69	0	4	1.33	1.010
PostQ11:Did your eyes feel itchy, gritty or sandy?	69	0	3	.59	.846
PostQ12:Did you feel sensitive to bright light?	69	0	3	.14	.522
PostQ13:During reading, did you feel the words moving or floating on the screen?	69	0	4	.41	.880
PostQ14:Look at the near target (letter E), do you have blurry vision at near?	69	0	4	.67	.980
PostQ15:Look at the near target, do you see two images (double vision) at near?	69	0	4	.49	1.009

PostQ16:Look at the far target (the page on the wall) do you have blurry vision at far?	69	0	2	.59	.714
PostQ17:Look at the far target (the page on the wall), do you see two images (double vision) at far?	69	0	3	.23	.622
PostTotal	69	1	33	**11.65**	6.719
Valid N (listwise)	69				

Appendix F: Comparison table between VDS and CISS

Survey/ # of items	VDS (17 questions)	CISS (14 questions)
Cognitive	Attention	Sleepy at near
	Thinking clearly	Concentration at near
	Remembering	Remembering
Body	Dizziness	
	Headache	Headache at near
	Body pain	Uncomfortable when reading
Internal Factors	Eye Strain	Eyes tired at near
	Pulling sensation	Pulling sensation
	Eye pain	Eye Pain at near
		Eye sore at near
Perception / Text	Moving words	Moving words at near
		Losing place when doing near task
	Blur at near	Blur at near
	Double at near	Double vision at near
	Blur at far	
	Double at far	
		Slow reading
External Factors	Dryness/Watery	
	Itchy, gritty or sandy	
	Photophobia	

Appendix G: Comparison table between VDS and Conlon Survey

	VDS (17 questions)	**Conlon Survey (23 questions)**
Cognitive	Attention	
	Thinking clearly	
	Remembering	
Body	Dizziness	
	Headache	Headache when working under fluorescent light
		Headache from reading a newspaper
	Body pain	
Internal Factors	Eye Strain	
	Pulling sensation	
	Eye pain	
Perception / Text	Moving words	Moving words when reading
	Blur at near	Blur when reading
		Squint at near
		Fade sensation of the words
	Double at near	Double vision when reading
		Maintaining clear image when reading
		Seeing more than one or two words on a line in focus
		Words spread apart
	Blur at far	
	Double at far	
External Factors	Dryness/Watery	
	Itchy, gritty or sandy	
	Photophobia	
		black print on white letters
		black print on a white background
		Move your eyes/rub/blink to see clearly?
		Flickering/shimmering words
		Under fluorescent lights, glare cause difficulty to read?
		Slow reading b/c one of the above difficulties?
		Flickering/shimmering background

		Viewing a striped pattern: watery, red, sore, strained, tired, dry, gritty, or do you rub them a lot
		Use a pen/finger to track the text
		Reading a newspaper: watery, red, sore, strained, tired, dry, gritty
		Re-reading the same words in a line
		Re-reading the line
		Working under fluorescent lights: watery, red, sore, strained, tired, dry, gritty