Original research article

Assessing Retinal Function Alterations Due to Digital Device Use: A Study of Computer Vision Syndrome in Medical Students

Abstract:

Digital devices, mainly smartphone with its time-consuming applications and 24/7 internet connection, are accused of the being the main cause of severe distraction and excessive disruptions with fragmentation of everyday life that adversely interrupts the adults and youth lifestyles, health, education and social or family relationships. The medical students underwent objective ophthalmic examination to confirm or exclude CVS diagnosis based on Iqbal's four major criteria for accurate CVS diagnosis. Screen-induced foveal dysfunction (SFD) has been recorded using the multifocal electroretinogram to prove the retinal function alterations due to excessive digital device use. Based on our outcomes, we have defined the term screen-induced foveal dysfunction (SFD) as "**the multifocal electroretinogram reduced foveal responses below standard normal ranges that are mostly temporary, reversible and usually associated with reduced visual acuities and performances in computer vision syndrome positive-cases**". SFD is characterized by temporary impermanent reduced foveal responses that associates reduced visual acuities and performances in CVS positive-cases. Strict reduction or cessation of exposure to digital screens and/or electronic devices that contains light emitting diodes (LEDs) for 4 weeks results in spontaneous resolution of cone adaptation/saturation thus eventually the

retina regains its normal foveal functions and responses with normal visual acuities and performances. Iqbal's instructions are helpful in reducing the medical students' screen-time to reverse the SFD thus improving the foveal responses in CVS positive-cases. It is recommended that the screen-time not exceed 3 hours daily to avoid the visual impacts and sequelae of the digital environment.

Keywords: Blue light; Computer vision syndrome; Digital eye strain; Multifocal electroretinogram; Screen-induced foveal dysfunction; Digital environment and digital screens.

Introduction

The innovative digital technology has occupied an enormous time of the individuals' daily activities and dramatically affected the modern lifestyle [1-5]. The digital environment means watching and interacting with several types of digital devices for extended periods through the entire day [1, 2]. The average screen-time in the digital environments reaches up to eight hours daily for the American adult interacting with ≥10 different types of digital screens [6, 7]. Within the digital environments, the routine exposure to various digital devices and electronic screens for several daily screen-hours has elicited various visual, ocular surface and extraocular symptoms and complaints known as the computer vision syndrome (CVS) or digital eye strain (DES) [1, 3-5]. The American Optometric Association (AOA) defined the computer vision syndrome (CVS) as follows "Computer vision syndrome, also referred to as digital eye strain, describes a group of eye- and vision-related problems that result from prolonged computer, tablet, e-reader and cell phone use" [8]. Meanwhile, the Tear Film & Ocular Surface Society (TFOS) considered DES as a more appropriate and specific tem than CVS and further redefined

DES as “the development or exacerbation of recurrent ocular symptoms and/or signs related specifically to digital device screen viewing” [1]. CVS is a multifactorial syndrome that affects more than one human system and its sequelae extend beyond the eye [3-5].

The CVS main visual symptoms are visual blur, eye strain/fatigue, seeing unclear objects post-screen use, glare/seeing halos of light around objects, feeling diminution of vision, double vision/diplopia, difficulty in refocusing the eyes, near vision discomfort/difficulty and increased sensitivity to light [1, 3-5, 8-18]. The CVS main ocular surface symptoms are dry eye, eye redness, itching/eye rubbing, watery eye, eye irritation/discomfort, foreign body sensation, burning sensation, heavy eyelids and frequent blinking [1, 3-5, 8-17]. The CVS main extraocular symptoms are headache, neck/shoulder/back pain, joint pain in fingers and wrists, inability to hold objects well, difficulty to write using a pen, sleep disturbances/insomnia and inattention [3-5, 8-18]. Other serious manifestations; mainly behavioral and mental health issues, such as depression, stress, anxiety, tendency to suicide and midnight hunger with weight gain have also been linked to CVS sequelae [3-5, 18-22]. However, both CVS visual and ocular surface symptoms could be attributed to accommodation disturbances, dry eye disease (DED), binocular vision dysfunction and contact lens wearing [1, 3, 4].

Digital devices, mainly smartphone with its time-consuming applications and 24/7 internet connection, have been implicated as being the main cause of severe distraction and excessive disruptions with fragmentation of everyday life that adversely interrupts the adults and youth lifestyles, health, education and social or family relationships [2, 3, 23]. Therefore, such subjects may encounter serious troubles in their lives such as low productivity, poor creativity and weak academic performance [2, 23]. However, it seems that the problem is not in the digital device or the smartphone itself, but the way people handle it and misuse it. In other words, digital devices

are not responsible for exacerbation of CVS but the way and manner it is been used is the actual problem [2-5]. The main risk factors and incorrect practices of the individuals' screen-styles are improper or too close eye-screen distance, screen edge at/above horizontal eye level, improper gaze angle (e.g. when lying down or in beds), improper or poor lighting conditions, screen- glare, poor screen- resolution or design, uncomfortable seating postures, watching screen in the dark, small screen-size, excessive screen brightness, small-font size, texting with both thumbs, prolonged screen-hours (average daily screen-hours exceeds five hours) and associated uncorrected refractive errors [3-5]. These risk factors constitute the digital screen or smartphone misuse or abuse practices that are responsible for development, exacerbation and aggravation of CVS [3-5].

Methods:

This study obtained the approval of the Institutional Review Board (IRB) in Faculty of Medicine, Sohag University, Egypt. This study was conducted in accordance with the tenets of the Declaration of Helsinki. Our study protocol included subjective information (CVS-F3 questionnaire; Appendix 1) and an objective ophthalmic examination of medical students. Prior to study enrolment, informed consent was obtained from these students after explanation of the nature and possible consequences of the study. Using an alpha level of 0.01 and the survey sample size determination table created by Bartlett et al. [24], we determined that the minimum sample size required for this study was 623 participants.

In the three published studies by Iqbal et al. [3-5], all medical students responded to the subjective valid and reliable computer vision syndrome form-3 (CVS-F3; Supplementary material 1) questionnaire (.742 Cronbach's alpha reliability coefficient, .773 Guttman Split-Half

Coefficient and 82% construct validity rate with the Pearson's correlation validity coefficient) that was designed to be ideal for University students [3-5].

Thereafter, the medical students underwent complete objective ophthalmic examination to confirm or exclude CVS diagnosis based on Iqbal's four major criteria for accurate CVS diagnosis [3-5, 9-13]. The complete ophthalmic examination included both uncorrected and corrected distance visual acuities (UDVA and CDVA; respectively) measurements, testing pupillary reflexes, DED tests, intraocular pressure measurement, subjective and cycloplegic refraction measurements, slit-lamp and dilated fundus examinations [3-5]. The exclusion criteria were amblyopia, strabismus, accommodation-convergence imbalance, near vision abnormalities, an isometropia greater than 2 diopters (D), myopia >6 D, hyperopia >4 D, astigmatism >4 D, eye or retinal pathology, current eye or systemic diseases and previous eye or systemic surgeries [3-5].

Furthermore, the medical students underwent multifocal electroretinogram (mfERG) examination. We used the mfERG device (RETIscan; Roland Instruments, Wiesbaden, Germany) in accordance with the standard protocol for mfERG of the International Society for Clinical Electrophysiology of Vision (ISCEV). The mfERG stimulus used in our studies was 61 hexagons in dilated subjects with system age-matched norms. The protocol adhered to ISCEV standards and our cut-off values were the normal ranges provided by the ISCEV standard protocol. Eventually, we documented the first foveal peak and amplitude density (P1 AD) in all the mfERG Rings and Quadrants.

Statistical analysis

Data was analyzed using STATA version 14.2 (Stata Statistical Software: Release 14.2 College Station, TX: StataCorp LP.). Quantitative data was represented as mean, standard deviation, median and range. As the data was not normally distributed Kruskal Wallis test for comparison of three or more groups and Mann-Whitney test was used to compare two groups. Qualitative data was presented as number and percentage and compared using Chi square test for trend, Chi square test or fisher exact test.

Binary logistic regression analysis was used to find factors affecting occurrence of CVS and linear regression analysis was used to find actors affecting the number of symptoms of CVS. Graphs were produced by using Excel or STATA program. P value was considered significant if it was less than 0.05.

Results:

CVS prevalence

We recorded 55.98% CVS prevalence rate among the medical students [4]. The CVS diagnosis was based on Iqbal's four major criteria for accurate CVS diagnosis [3-5, 9-13].

Figure 1 shows comparison between males and females as regards CVS-complaints. Figure 2 shows the distribution of studied students according to their CVS-complaints. Figure 3 shows the association between CVS-complaints and type of the commonest screen used. Figure 4 shows the association between CVS-complaints and how students studied medicine.

CVS-F3 logistic regression analyses

Tables 1, 2 and 3 summarize the multivariate logistic regression analyses of factors affecting occurrence of CVS, blurred vision and dry eye; respectively.

Ophthalmic examination and MfERG outcomes

Table 4 summarizes the outcomes of the CVS versus control groups. Tale 5 shows the mfERG findings before and 4 weeks after reduction of screen-hours in the CVS group while Table 6 shows the correlation between the differences of screen-hours/day and the differences of mfERG parameters.

Figure 5 shows the mfERG outcomes with reduced foveal responses of a medical student in the CVS group. Figure 6 shows the mfERG outcomes of another student before and 4 weeks after reduction of screen-hours in the CVS group with improvements in the foveal responses. During these 4 weeks of strict screen-time reduction, all CVS positive cases followed Iqbal's instructions (Iqbal's anti-CVS protective measures) [5, 10, 18].

Discussion

We have exhibited that the digital environment including the digital devices and electronic screens that LEDs that emits blue light, affects the macular integrity as we have already documented the existence of the screen-induced foveal dysfunction (SFD) in our three published studies [3-5]. We are the first ophthalmic team that investigated the mfERG foveal changes elicited by the exposure to blue light emitting-screens. These mfERG changes exhibited the reduction in foveal responses representing the foveal dysfunction that was associated with corresponding reduction in visual performances and acuities. The SFD was recorded in the university students diagnosed as positive CVS-cases who watching digital devices for prolonged

screen-hours (>5 average screen-hours) with extensive exposure to various types of blue light emitting-screens such as laptops, smartphone, pads/tabs and/or desktop devices [3-5]. Interestingly, most of these positive CVS-cases were medical students who were involved in the University mandated computer system use program.

Our studies included two groups; the control and the CVS groups. The control groups involved medical students that had no-CVS diagnosis, spending less than three daily screen-hours on average, exhibited normal mfERG findings that revealed within normal preserved foveal peak and mfERG Quadrants and Rings were within ISCEV standard protocol normal ranges. On the other hand, CVS groups included medical students that had positive CVS diagnosis that was based on Iqbal's four major criteria for accurate CVS diagnosis [3-5, 9-12], spending more than five daily screen-hours on average, exhibited abnormal mfERG findings with statistically significant foveal amplitude reduction in P1 AD in most of the mfERG Quadrants and Rings below ISCEV standard protocol normal ranges [3-5]. In comparison with the control groups, the CVS groups exhibited a statistically significant foveal amplitude reduction in the uncorrected and the corrected distance visual acuities (UDVA and CDVA; respectively) [3-5].

Furthermore, we discovered that the SFD is a potential reversible phenomenon [5]. We recorded both the mfERG changes and associated visual acuities before and 4 weeks following strict reduction of the screen-time to ≤1 screen-hour daily in both the control and the CVS groups [5]. Thereafter, the medical students in the CVS group exhibited remarkable statistically significant improvements in mfERG foveal responses near to normal ranges with correlated improvements in both UDVA and CDVA [5]. We also documented a positive correlation between the differences of average daily screen-hours reduction and the differences in mfERG Quadrants and

Rings P1 AD [5, 10]. Therefore, the lower the daily screen-hours with less exposure to the blue light emitted from digital screens, the more the improvements in the foveal responses [10].

Meanwhile, SFD in positive CVS-cases and is usually associated with blurring of vision, feelings of diminution of vision, halos around objects with reduced visual performances. In addition, we think that the SFD is a potential type of retinal phototoxicity that could be attributed to excessive exposure to blue light emitting LEDs, encountered in the manufacture of modern digital screens and electronic devices, with subsequent photochemical injury [3-5, 9-12]. Furthermore, we have discovered that SFD is a temporary retinal phototoxicity phenomenon that has short-term adverse impacts on normal foveal functions and intact macular integrity. Moreover, SFD might be reversed by restrict reduction of the screen-time thus minimizing the retinal exposure to blue light emitting screens [9-12]. Meanwhile, we unfortunately don't know underlying pathophysiological mechanisms of SFD; however, it might be could be caused by the macular cone/bipolar cell dysfunction due to the cone adaptation and/or saturation resulting from the excessive levels of blue light with a potential level of retinal phototoxicity resulting in a photochemical injury inducing SFD.

Similar to our outcomes, Cougnard-Gregoire et al. [14] concluded that the potential toxicity of long-term cumulative exposure to blue light emitting LEDs and the dose-response effect are currently unknown. In agreement with our results, Li et al [25] reported the mfERG outcomes that ≥8 daily hours viewing of the screens reduced the retinal photoreceptor cells amplitude in the parafoveal region of the macula with delayed peak time. They also stated that the long-term exposure to blue light is a cause of structural and functional damage of the retinal tissue [25].

Moreover, Eni CG and Uahomo PO [17] documented a significant association between increased screen time and reduced normal visual acuity that concedes with our outcomes as we exhibited a negative correlation between the differences of the daily screen-hours and UDVA, i.e. the lower the daily screen-hours the better the UDVA [5, 10]

Conclusions

Based on our outcomes, we have defined the term screen-induced foveal dysfunction (SFD) as "**the multifocal electroretinogram reduced foveal responses below standard normal ranges that are mostly temporary, reversible and usually associated with reduced visual acuities and performances in computer vision syndrome positive-cases**" [3-5, 9-12]. Therefore, SFD could be discovered in positive CVS-cases and is mostly associated with blurring of vision, feelings of diminution of vision, unclear visualization of objects especially post-screen use, complaining of annoying halos of light around objects with subsequent reduction in visual performances. Furthermore, SFD is a potential type of retinal phototoxicity that could be reversed by strict reduction or cessation of exposure to digital devices and electronic screens for 4 weeks that results in spontaneous resolution of cone adaptation/saturation thus eventually the retina regains its normal foveal functions and responses with normal visual acuities and performances.

Finally, our studies recommended that the higher educational authorities should re-plan the mandated computer system use program and consider other alternatives. We also recommend that further future studies including mfERG investigations regarding this topic.

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Ethical Approval and Consent:

The three studies by Iqbal et al. gained the approval of the Medical Research Ethics Committee (MREC) in Faculty of Medicine, Sohag University, Egypt. All three studies were registered as clinical trials at the ClinicalTrial.gov (ID: NCT04398212 and NCT04405648) and the Pan African Clinical Trial Registry (PACTR201811618954630). All studies were conducted in accordance with the tenets of the Declaration of Helsinki. All participants signed an informed consent prior to enrolment in the studies.

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Appendix: 1

Computer Vision Syndrome Form-3 (CVS-F3) Questionnaire

Please mark your answers (√): (University) Date: Name:

- **Age: 16 17 18 19 20 21 22 23 24 25 26**
- **Gender: Male Female**
- **How many hours do you spend on your digital screen every 24 hours (total screen-hours)?**
  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
- **How many of your total screen-hours do you spend on your digital screen during the daytime?**
  0 1 2 3 4 5 6 7 8 9 10 11 12
- **How many of your total screen-hours do you spend on your digital screen at night?**
  0 1 2 3 4 5 6 7 8 9 10 11 12
- **How many years have you spent using screens in this manner?**
  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
- **Do you spend most of your screen-hours during the day or at night? Day Night**
- **The hours you spend on your digital screen are? Continuous Interrupted**
- **What are the digital screens you commonly use? (Please select one or more answers):**
  Desktop computer Laptop iPad/Tab Apple smartphone Android smartphone others
- **What is the most common primary/single screen you use? (Please select one answer only):**
  Desktop computer Laptop iPad/Tab Apple smartphone Android smartphone others
- **What is the screen-size of the most common individual/single screen you use?**
  Small-sized screen Medium-sized screen Large-sized screen
- **What is the screen-version of the most common individual/single screen you use?**
  New-version screen (within last 2 years) Old-version screen
- **To what average level do you illuminate your primary screen (i.e., screen-brightness) in the dark?**
  10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
- **Do you have any of the following symptoms frequently with screen use over last 12 months? (Please select all answers that apply; if none apply, leave blank):**

Ocular symptoms:

Blurred vision		**Eye strain and fatigue**		**Difficulty in refocusing the eyes**	
Dry eyes		**Eye redness and irritation**		**Near vision discomfort/difficulty**	
		Double vision/diplopia		**Unclear objects post-screen use**	

Extraocular symptoms:

Headache		**Insomnia**		**Neck/shoulder/back pain**		**Inability to hold objects well**	
		Depression		**Joint pain in fingers and wrists**		**Difficulty to write using a pen**	

- **How many symptoms-attacks on average, if any, you suffer from every month over last 12 months?**
  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
- **How many years, on average, do you suffer from these symptoms-attacks, if any?**
  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
- **Are your symptoms-attacks associated with screen use? N/A Yes No**
- **Do you have previous diagnosis of dry eye disease or use eye drops to treat it? Yes No**

- **Do you have any refractive error or wearing glasses? Yes No**
- **Do you wear contact lenses or have contact lenses related diseases? Yes No**
- **Do you have previous eye or systemic disease or surgery? Yes No**
- **Do you feel that digital screens affect your lifestyle and eye health? Yes No**
- **Are you willing to decrease your screen hours to guard against CVS? Yes No**
- **Is your medical school involved in mandated computer system use program? Yes No**
- **How do you usually study medicine? Screens alone Books alone Both**
- **What is the main screen you usually use to study medicine? Desktop computer Laptop iPad/Tab Apple smartphone Android smartphone Others None**
- **What is your main purpose that consumes most of your screen-time? (Select one answer only): Medicine/Science Social communication/Entertainment others**
- **Do you have any of the following practices frequently with screen use? (Please select all answers that apply; if none apply, leave blank):**

Poor screen- resolution or design	☐	**Screen- glare**	☐	**Poor lighting conditions**	☐
Screen edge at/above horizontal eye level	☐	**Close eye-screen distance**	☐	**Watch screen in the dark**	☐
Uncomfortable seating postures	☐	**Small-font size**	☐	**Texting with both thumbs**	☐

Consent: By completing this survey, I agree that the data or outcomes of CVS-F3 and/or ophthalmic examination will be used as a part of CVS research project for publication worldwide.

Yes No