The Interplay of Screen Brightness and Sustained Use on Digital Eye Strain and Visual Performance in High School Students: A Narrative Review

Zhenxiang Gao *

WLSA Shanghai Academy, Shanghai 200940, China

* Corresponding Author Email: gaozhenxiang1025@outlook.com

Abstract. The increasing use of electronic devices is contributing to a growing incidence of Digital Eye Strain (DES) in the student population. This literature review discusses the correlation between two main independent variables that contribute to the development of DES: screen brightness and duration of use. While a well-established risk factor for DES is excessive duration of electronic usage, recent studies show an independent relationship between the difference in screen brightness and ambient lighting relative to the occurrence of DES regardless of duration of use. The review also describes the physiological basis for experiencing visual discomfort because of damage to the ocular tear film and disturbance of the circadian rhythms, as well as how environmental elements can play a role in visual fatigue. Factors influencing visual fatigue include device usage duration, environmental lighting conditions, text contrast, and user behavior. Finally, the review provides practical recommendations from the research to help reduce the prevalence of DES among adolescents.

Keywords: Digital Eye Strain; Screen Brightness; Adolescents; Visual Fatigue; Computer Vision Syndrome.

1. Introduction

New technological advancements have impacted how adolescents live by incorporating electronic devices into nearly every aspect of their educational experience, socializing, and entertainment activities. Daily interaction with electronic screens is common for most high school learners. Therefore, the majority of a student's day is spent using screens for classroom instruction, completing assignments, and interacting with peers [1].

Remote learning during the COVID-19 pandemic has resulted in an increase in the number of hours spent using electronic devices for learning and communicating with other students. Consequently, this surge in screen time is exerting a substantial negative effect on both the mental and physical health of adolescents [2].

Modern technology has produced many advantages due to a multitude of resources and flexible ways to perform tasks; however, an evaluation of how visual health has changed because of the advancing technology is required [3]. The negative impact of electronic devices (such as computers and tablets) on adolescent vision is well-documented, and adolescents who are facing these challenges may face significant difficulties in achieving their full potential academically, socially, and professionally [4]. Specifically, Digital Eye Strain (DES), also known as Computer Vision Syndrome (CVS), has emerged as a growing issue resulting from increased technological dependence. Studies indicate that DES includes a variety of different vision-related ailments (such as blurred vision, dry eyes, irritated eyes, headache, and difficulty focusing) [1, 5].

DES is affected by many factors, but the two main things reviewed in this article are: 1) screen brightness and 2) screen usage time. The brightness level of a screen should be equal to the brightness of the area surrounding it. When there’s an extreme difference between the two, the muscles have to work harder to improve readability and this leads to greater fatigue of the eyes [6]. For example, using a dimly lit monitor in daylight compromises text legibility. A similar effect happens with a brightly lit monitor at night in a darkened room. As the monitor becomes more brightly illuminated, the amount of work needed to focus the eyes and read the text becomes even greater [7]. Prolonged periods of time spent using a computer without taking a break also causes less involuntary blinking, which can cause dryness in the eyes. Prolonged periods of computer use can also lead to greater accommodative stress, which can occasionally result in temporary myopia and accommodation spasm [8].

While extensive discourse exists regarding the individual impacts of screen duration and brightness, there is a paucity of research examining how these two variables interconnect to affect adolescent health. This article posits that screen brightness and usage duration synergistically influence the development of DES and adolescent ocular function; these two distinct but interrelated variables work together to exacerbate visual system issues. This article is going to examine the literature available that addresses how the two variables interact with one another and also offer strategies for maintaining good visual health and visual performance in adolescents.

2. Methodology

The relationship that exists between screen usage and visual health is described in this narrative review. Articles were obtained from PubMed, Google Scholar, and IEEE databases using search terms including Digital Eye Strain, Screen Brightness, and Adolescents. The selection was limited to peer-reviewed studies involving human subjects that were published in English between 2014 and 2024. Animal studies and studies related to non-ocular disease processes were eliminated from the selection process.

3. The Physiological Impact of Screen Characteristics

Many studies have demonstrated that long duration and specific characteristics of screen use are two of the most significant causes of DES [9]. Existing research on DES predominantly investigates two primary etiologies: the inherent characteristics of modern displays and the duration of screen exposure.

3.1. Screen Light Characteristics and Mechanisms

One important area in research focuses on investigating the negative effects of the light emitted by screens, particularly those screens using light-emitting diode (LED) backlight technology.

3.1.1 Blue Light and Retinal Contrast

According to research, the blue light spectrum (415–455 nm) is associated with tremendous amounts of energy and contributes significantly to visual discomfort and fatigue [10]. It is theorized that high-energy wavelengths produce many of the risk factors associated with eye diseases, as well as directly cause eye strain. The blue light's effect on retinal contrast will ultimately force continuous ciliary muscle contraction to maintain focus.

3.1.2 Circadian Rhythm and Systemic Effects

In addition to the risk of direct eye discomfort from screens, blue light emitted from screens can also have long-term effects on overall health by disrupting circadian rhythms. Recent reviews of what is currently known about the physiology of these cells demonstrate that these retinal cells are very sensitive to blue light (approximately 480 nm): Ocular exposure to blue light at night decreases the production of melatonin, which regulates sleep [11]. Since many students use devices late at night, this melatonin suppression often leads to delayed sleep onset and reduced sleep quality. Poor sleep quality impedes ocular recovery from daily stress, establishing a deleterious cycle wherein systemic fatigue exacerbates ocular symptoms [11, 12].

3.2. The Physiological Impact of Usage Duration

In addition to light quality, the duration of use itself is considered a major factor in evaluating the severity of digital eye strain. However, the mechanism is not merely "tired muscles" but involves complex ocular surface dynamics.

3.2.1 Tear Film Instability and Blink Rate

Extended screen use significantly destabilizes the tear film. In the average person, the tear film keeps lubricated by blinking approximately 15 to 20 times per minute. However, the research of Korb et al showed that during extended periods using digital devices, blinking is significantly decreased (only 5–7 times/min) [13]. Additionally, blinking becomes increasingly incomplete (i.e., the eyelids do not fully close). The decrease in blinking leads to increased evaporation of the tear film, and therefore, more of the corneal surface is exposed to the air. Evaporation of the tear film on the ocular surface leads to the development of evaporative dry eye and symptoms associated with evaporative dry eye — including burning, gritty feeling, and fluctuating vision – described as the hallmark signs of Dry Eye Syndrome [13, 14].

3.2.2 Accommodative Load and Risk Thresholds

Recent studies suggest that while short-term use is benign, prolonged engagement (exceeding 2 hours) triggers DES [2, 15]. Prolonged digital media engagement may impair the natural accommodation and ciliary muscle activity required to maintain effective focus [16].

4. Environmental Moderators and Interaction Effects

While these studies confirm a physiological basis for DES, emerging research suggests the relationship between screen conditions and visual fatigue is non-linear. Another viewpoint suggests that development of DES is a product of multiple factors and that its occurrence may be affected by a range of environmental and behavioral influences.

4.1. The Importance of Environmental and Behavioral Moderators

Health organizations concur that DES is the result of many factors working together to create adverse effects on users of computers, phones and other digital devices, but not exclusively from those devices. For instance, many clinical practice guidelines identify multiple causes of visual discomfort from computer use in addition to the use of computers and mobile phones; these causes include decreased frequency of blinking (typically seen with dry eyes), increased light exposure (such as direct exposure to bright lights), incorrect distance and angles of view, uncorrected refractive errors (i.e., not wearing appropriate glasses), and glare from bright light sources [1]. Understanding these additional causes highlights the importance of user behaviors in relation to the development of DES, as well as the technologies used by users.

4.2. The Contrast and Relative Brightness Argument

Some researchers dispute the notion that high brightness alone is harmful, arguing instead that visual comfort depends primarily on the contrast between the screen and its environment [17]. These researchers conclude that visual comfort is determined not by absolute screen brightness, but by the contrast ratio between the display and the ambient lighting [6, 7]. A display may appear to be "too bright" when viewed in a dark environment, but it may appear "too dark" when viewed in a bright environment (e.g., outside during the day, or in an office building during the day). Conversely, a display will create the illusion of being too dim or too bright depending upon the amount of contrast created between the display and its reflective surroundings. When contrast becomes excessive or too little (for example, a glare, or reflection) visual discomfort will occur. Therefore, all screen settings should be changed dynamically based on the ambient lighting conditions of the specific usage environment.

4.3. Text Polarity and Display Mode

A prevalent argument regarding the environmental impact of a computer's display is the relative "text polarity," also known as "dark mode" (black background with white text) and "light mode" (white background with black text). Many students favor dark mode due to its ability to reduce glare; however, according to several ergonomics' studies, dark mode does not improve legibility over light mode.

Ergonomics studies have demonstrated that reading text with dark letters on a light background creates a positive polarity between the dark letters and the light background. This is due, in part, to the increased total amount of light being emitted from the light source, which causes the pupil to constrict (dilated pupils produce an enlarged aperture). When the pupil is smaller, it produces a "pinhole effect," which enhances the depth of field and the quality of the retinal image. As such, using light mode enhances the user's ability to proofread effectively and minimizes visual fatigue when reading for long periods of time and making corrections [18].

5. Discussion

The goal of this review was to combine current research evidence regarding the adverse effects of screens with the most up to date recommendations on screen time for adolescents. There is a significant gap between the two. Current research has focused primarily on either the physiological effects or the behavioral and environmental aspects associated with screens (either viewed alone or together). The first group of articles primarily examines the physiological aspects of exposure to light and time spent looking at screens, while the second group examines the environmental and behavioral factors contributing to these effects. In summary, when combining all of these findings, it appears that both the intensity of light emitted by the screen and the length of time spent looking at the screen have a cumulative impact on visual fatigue.

It has been found through analysis of the data that suboptimal brightness levels worsen the negative effects of using screens, and this is often referred to as a "threshold effect." During extended engagement with video games or movies, intense focus often suppresses the blink reflex, reducing the rate to as few as five to seven blinks per minute [5]. In these instances, the eyes' surface becomes dry resulting in irritation; this happens more quickly when the brightness setting on the monitor or television is not adjusted correctly.

5.1. Evidence-Based Mitigation Strategies

In addition to addressing physiological and environmental aspects of risk factors associated with video monitor usage, many of the same groups have recommended that users follow the "20-20-20 rule" [1, 5]. The premise of this recommendation is that every 20 minutes, users should take a 20-second break to look at something at least 20 feet away from them. This helps relieve the stress on the ciliary muscles (the muscles that focus) caused by extended near-vision activities and resets the rate of blinking, thus allowing the eyes to be rehydrated through blinking.

Students are also interested in the use of optical aids (specifically blue light blocking glasses). Advertising promotes this product as an answer to Digital Eye Strain (DES). Also, A systematic review of the current literature by the Cochrane Database identifies that there is no high-quality evidence demonstrating that these glasses decrease visual fatigue [19]. Therefore, students should be encouraged to correct their workspace using environmental adjustments instead of relying on passive filtering through glasses. Recommended adjustments include tilting screens 10–20 degrees downward to reduce ocular surface exposure and modifying ambient lighting to minimize glare.

5.2. The "Goldilocks" Zone of Brightness

Current findings suggest that extreme brightness levels are potentially detrimental. The current research suggests that the best approach is to find the "Goldilocks" level of ambient light and brightness for use with electronic devices. For example, using an electronic device with a very bright screen in a completely dark room will produce retinal-damaging glare, whereas a very dim screen in a bright room forces the eyes to strain for clarity. Consequently, public health guidelines should emphasize environmental management alongside screen time reduction. One practical recommendation for high school students is that they should use "Dark Mode" or equivalent (white text on a black background) in low light environments and increase the ambient lighting if using the device in bright light instead of simply reducing the brightness on the screen.

5.3. Limitations and Future Research

The limitations of this review should be acknowledged. Most of the research included is based on cross-sectional or short-term laboratory experimental data. There are currently few longitudinal studies examining how changes in screen brightness settings cumulatively affect the eyesight of adolescents over time (e.g., several months or years). Also, the extent of DES may differ from one person to another depending on uncorrected refractive errors and genetic characteristics. Notably, individual differences were not detailed in the reviewed studies. Future studies should focus on conducting research in actual classrooms to determine the optimal brightness to ambient light ratio that provides maximum visual comfort for the developing vision of adolescents.

6. Conclusion

The literature examined in this review provides strong evidence that DES is a multifactorial disorder, which arises from interrelated factors associated with screen brightness, ambient lighting and the length of time a young person uses screens. Prolonged screen usage is the single largest risk factor for developing DES; however, it has been shown that this risk can be increased substantially if the user’s screen brightness is not set properly. The increase in eye strain caused by the difference between the screen's brightness and the ambient light level, combined with differences in individuals' physical make-up, contributes to a higher risk for most people. Therefore, in addition to limiting how much time individuals spend viewing their screens, future strategies will need to emphasize ergonomic education on how to use light devices safely by establishing ambient and device brightness levels to optimize comfort.

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