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Computer vision syndrome as a growing challenge in ophthalmology. A review of current knowledge



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HIGHLIGHTS

Computer vision syndrome is a growing problem in the digital era – appropriate prevention helps protect vision and improves daily comfort.

ABSTRACT

For several decades, we have observed a dynamic increase in the use of screen devices, which have become an integral part of everyday life. Modern life, in which conferences, working from home, entertainment, and online shopping are commonplace, contributes to the development of computer vision syndrome. Prolonged exposure to screens and improper use of them cause the symptoms of the syndrome: eye strain, dryness, irritation, headaches, and concentration problems. This article analyzes risk factors, symptoms, and current preventative strategies. It justifies the need to raise awareness and promote a healthy lifestyle among users of digital devices.

Key words: computer vision syndrome, CVS, video display terminal syndrome, VTD, blue light, eye fatigue, dry eyes, ergonomic workstation setup, screen time

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INTRODUCTION

There has been a marked increase in the use of video display terminals (VDT) in recent years, which have become an integral part of everyday life. VDT is a term used to describe all devices that have a screen and allow the user to interact with digital content. Smartphones, tablets, computers, televisions, e-readers, navigation systems, and other devices equipped with screens have a key impact on how we communicate, work, learn, and spend our free time.

Since March 2020, when most countries introduced restrictions aimed at limiting the spread of the SARS-CoV-2 virus, fulfilling professional and academic duties in person became impossible, which forced an even greater adaptation of technology to online functioning. Although initially the organization of work and education at a distance was seen as a temporary solution, in many cases, it became an integral part of everyday life. Unfortunately, these changes are not neutral to our bodies. With the increase in the use of screen devices, we proportionally experience health consequences that affect various organs, including the organ of sight.

A collection of ailments and health symptoms that appear as a result of prolonged use of screen devices is defined as computer vision syndrome (CVS), also known as digital eye strain (DES), video display terminal syndrome (VDTS) [1] or eye fatigue (VF) [2].

RISK FACTORS

In the context of many ailments, including digital eye strain, identifying risk factors plays a key role in undertaking effective preventive measures. CVS is a condition with a multifactorial etiology, and its risk factors include both the specificity of working with electronic screens, individual health predispositions, and environmental conditions.

Publications confirm that symptoms are more often experienced by women than by men [3–6]. Results indicate that the highest incidence of CVS was recorded in Africa (71.2%) and in Asia (69.9%). In Latin America and Europe, symptoms occurred with a slightly lower frequency, reaching 66.6% and 60.9%, respectively. These differences may be the result of both varying access to technology and differences in lifestyle and health factors in particular regions [5].

One of the main factors is the time spent in front of the screen. In statistics, prolonged exposure to screen devices correlates with the occurrence of digital eye strain symptoms [6, 7].

Individual health factors that increase the risk of VDTS include improperly corrected refractive errors of the eye [4, 8–10], as well as diseases leading to insufficient tear production or reduced tear quality, including inflammation of the lacrimal gland in the course of infectious diseases, hormonal disorders, or dry eye syndrome (DES or Dry Eye Disease, DED) [8]. People who regularly wear contact lenses are more prone to developing the syndrome [3], and the risk increases further with the use of screen devices for more than 6 h a day [11].

Polluted air, low humidity, air conditioning, and high temperatures in rooms where screen monitors are used exacerbate the risk of dry eyes and intensify CVS symptoms [8, 12–14]. A non-ergonomic workstation with digital devices, such as improper screen and lighting settings as well as incorrect body posture, is another risk factor [15, 16]. Additionally, using screens with low resolution, poor contrast, or incorrect brightness settings forces the eyes to greater effort, which promotes the development of CVS [4, 17].

PATHOPHYSIOLOGY

Changes in blink rate and tear film

Blinking plays a key role in maintaining homeostasis of the ocular surface. Eyelid movements spread the products of the lacrimal, mucous, and Meibomian glands. The tear film's optically smooth surface enables light to be focused sharply on the retina, ensures hydration and moistening of the corneal and conjunctival epithelial cells, protection against pathogens, and secures the stability of the tear film. We distinguish three types of blinking: spontaneous, voluntary, and reflexive. Within spontaneous blinking, we further distinguish between complete blinking (with complete contact of the upper and lower eyelids) and incomplete blinking (without complete contact of the eyelids) [18].

Physiologically, a person blinks about 15–20 times per minute, but when using screen devices, this frequency drops to 4–6 blinks [19–21]. However, few available publications indicate that the intervals between them are reduced during VDT use [22]. The frequency of blinking is also influenced by using a device with insufficient image quality (resolution, contrast, brightness) and font size [4]. In addition, the frequency of blinking and the increase in intervals between them are conditioned by squinting caused by glare or refractive error [23]. Lack of regular eyelid movement moisturizing the corneal surface is responsible for the symptom of dry eye, which develops mainly as a result of water loss through evaporation, leading to tissue damage as a result of hyperosmolarity of the tear film [24].

People who stare at screens for long periods of time, in addition to the disturbance of tear distribution, have a much faster tear film break-up time (TBUT) [20, 25]. However, the stability of the tear film and the occurrence of CVS symptoms are most affected by incomplete blinking [26], the amount of which increases with the time of use [27] and its frequency correlates with the occurrence of dry eye symptoms [22]. Tear film breakup is responsible for spontaneous blinking, which leads to its renewal. However, in users of screen devices, when the regularity of eyelid clo-

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sure decreases, the surface of the eye remains unprotected for longer, which causes burning, itching, redness, and dry eyes [20].

Women suffer more often from dry eyes [7, 12, 28], which results from several factors. In addition to blinking disorders that occur during the use of digital devices, women are characterized by a shorter TBUT. Sex hormones play an important role: androgens, the level of which is lower in women, affect the quality and quantity of lipids produced by the Meibomian glands, responsible for the stability of the tear film [29]. Testosterone stimulates the growth and activity of the lacrimal glands, increasing their secretion. Estrogens act in reverse, reducing lipid production and impairing the integrity of the tear film [30, 31]. Cosmetics migrating to the surface of the eye during application, makeup removal, or simply wiping the eye disrupt the composition and functionality of the tear film [32, 33].

The mechanisms during VDT use contribute to an increase in tear fluid loss by reducing its stability or faster evaporation, but do not affect the reduction of its secretion [25] as in dry eye syndrome [12].

Failure of adaptive eye mechanisms: accommodation, oculomotor function, and refraction

Looking at close objects on screens, especially cell phones, requires the proper functioning of the accommodation system and convergence mechanisms, which are essential for obtaining a sharp and unified image [34].

Factors such as presbyopia (caused by loss of lens elasticity) and uncorrected refractive errors (myopia, hyperopia, astigmatism) further disrupt the eye's adaptive processes to changing distances, increasing subjective visual discomfort and symptoms of CVS [35, 36].

Staring at a screen from a fixed distance leads to a weakening of the ability to perform dynamic oculomotor changes, a decrease in accommodation amplitude, the development of exophoria (the tendency for the eyes to diverge when looking at close objects) [37], and even esotropia [38]. Symptoms of these disorders include blurred vision, asthenopia (eye strain), double vision, eye pain, and tension headaches. One of the most frequently reported consequences of prolonged use of screen devices is impaired visual acuity. Proper focusing of the image on the retina, which is crucial for clear vision of small details, can be disrupted by fatigue of the visual system and abnormalities in the functioning of the tear film – the basic optical element of the eye. As described above (paragraph: Changes in blink rate and tear film), the use of VTD adversely affects its quality and distribution, resulting in refractive distortions and degradation of image quality [8]. These abnormalities are particularly evident in people with existing refractive errors, which – if left untreated – intensify accommodative effort and accelerate the development of CVS symptoms. Therefore, proper optical correction is of key importance for screen users. Even a small refractive error, amounting to ≥0.5 D, increases discomfort and reduces productivity when working with screen devices [9, 39, 40].

Blue light as a factor in visual stress and sleep disturbances

The light emitted by most LEDs in displays appears white, but their highest emission occurs in the blue light range (400–490 nm). In contrast to the phototoxic effects of intense blue light, the low-intensity blue light emitted by displays does not cause immediate damage to the retina [41]. However, there is a risk of cumulative, long-term effects resulting mainly from increased oxidative stress and increased production of reactive oxygen species (ROS) in photoreceptor cells [42–44].

With age, the lens of the eye yellows, which reduces the transmission of light, including blue light. For this reason, older people are relatively less exposed to blue light than younger people, whose lenses have high permeability [45].

Research results demonstrate that short-wavelength electromagnetic radiation generated by electronic devices contributes to the initiation of dry eye syndrome symptoms [44], tear film destabilization, and the development of asthenopia. Prolonged use of devices emitting this type of radiation can lead to CVD, manifesting as a complex of characteristic symptoms [46].

A recognized measure of fatigue and eye strain is the critical flicker fusion frequency (CFF), at which flickering light ceases to be perceived as flickering and begins to be perceived as a continuous light source. As a result of prolonged staring at a computer screen, the CFF decreases, which causes the flickering to become more noticeable. The decrease in CFF is associated with reduced retinal activity, particularly sensitive to blue light [47] and with the occurrence of CVS symptoms [46]. Unfortunately, in studies, changes in CFF did not always correlate with the subjective sensations of the subjects [48].

Attention is also drawn to the negative relationships between exposure to artificial light and impaired sleep quality and reduced daytime alertness. Melanopsin, a photopigment found in specialized retinal ganglion cells (ipRGCs), is particularly sensitive to light with a wavelength of approximately 460 nm (blue light). Studies have shown that maximum melatonin suppression (λmax) occurs with exposure to light at a wavelength of approximately 460 nm, which confirms the key role of melanopsin in regulating melatonin secretion by the pineal gland and its influence on the circadian rhythm [45, 49]. Delayed sleep onset, reduced sleep quality, and reduced sleep duration correlate with a longer overall average time spent in front of a screen [50]. Thus, a vicious cycle is created: insomnia leads to reaching for a phone or laptop again in bed, in a dark room [34, 50].

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Discrepancies in research methodology and the characteristics of studied populations result in ambiguous study results. Therefore, the role of blue light in CVS remains a controversial issue and a subject of debate, particularly with regard to its impact on eye fatigue and vision.

The impact of lighting and screen parameters on eye strain

Light has a significant impact on visual comfort when working with digital devices. Improper lighting in the workplace, whether natural or artificial, can contribute to the intensification of CVS symptoms [51]. A screen that is too bright can cause glare and force the eyes to work harder to adapt to the lighting conditions, leading to faster eye fatigue. Conversely, a screen that is too dark can make it difficult to distinguish details on the display.

Asthenopia, which is a weakening or fatigue of the eyes or vision, is one of the main symptoms of CVS and is significantly related to the amount of time spent using VDT [52]. Spasms of the eye socket muscles, caused by low contrast or glare [10] originating from the digital display or from the lighting in the surrounding environment, contribute to its occurrence. It is important to position the computer screen to avoid glare from overhead lighting or windows [6]. The symptoms of asthenopia can be even worse when reading from a smartphone in the dark [34]. It has been proven that phone usage among young people increases intraocular pressure (IOP), and dim lighting exacerbates this effect [53].

Adjusting screen contrast, color temperature, and other settings to increase comfort and meet individual needs may be beneficial, but further research is needed to determine their effectiveness [21].

Incorrect posture and its consequences

Prolonged staring at a screen with improper posture (e.g., sitting in a hunched position) can lead to tension and pain in the muscles of the neck, back, and shoulders. The size and resolution of the device influence the user's body posture during its use. The smaller the screen, the shorter the distance to the user's face to maintain visual comfort [17].

Among mobile device users, the most common musculoskeletal complaints involve the neck [54], which is strained by constantly tilting the head downwards. Studies point to a link between using a mouse while working on desktop computers and an increased risk of neck pain [55], right arm pain, and tension neck syndrome [56]. Neck tension can also be caused by a lack of support or an unnatural position of the forearms [57].

A screen that is set too high, especially in the case of desktop computers, forces frequent tilting of the head or wide opening of the eyelids. Increased corneal exposure associated with a higher viewing angle causes an enlargement of its surface area, which in turn accelerates tear film evaporation and promotes incomplete blinking. Analyses confirm that a higher monitor position correlates with eye fatigue and reduced work efficiency [39].

SYMPTOMS

Symptoms of CVS encompass a wide range of visual, ocular, musculoskeletal, and behavioral ailments [1], the diversity of which depends on the type of device and the time and circumstances of its use (tab. 1). Although using VDT leads to various extraocular symptoms, the most frequently reported problems are visual ailments [39]. In most cases, symptoms appear when the visual demands of a task exceed a person's visual capabilities, hindering comfortable performance [58]. However, the ailments subside after ceasing the use of digital devices. Initially, the symptoms may seem harmless, but their intensification and chronic nature can negatively affect quality of life and productivity, both at work and in private life.

DIAGNOSIS

Despite the increasing number of studies, there is no universal and unambiguous method for documenting the actual prevalence of this condition worldwide. The reliability of

TABLE 1

Symptoms of CVS [40, 58, 59].

Accommodative disorders	Ocular symptoms	Extraocular symptoms
• blurred vision	• dry eye disease	• neck pain
• receded near point of convergence	• excessive blinking	• back pain
• distance blur	• foreign body sensation	• shoulder pain
• accommodation problems	• ocular pain	• arm pain
• double vision (diplopia)	• excessive tearing (epiphora)	• headache
• colored halos around bright objects	• itching	• depression
• subjective visual deterioration	• burning sensation	
• light sensitivity (photophobia)	• irritation	
• difficulty focusing on printed text	• eye fatigue	
	• redness	
	• heavy eyelids	

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available epidemiological data is limited by the lack of objective ophthalmological assessment of participants and inconsistent criteria for defining CVS in different studies [60]. In most analyses, only validated structural questionnaires are used. Currently, the most frequently used tools are the Computer Vision Syndrome Questionnaire (CVS-Q) and the Computer Vision Symptom Scale (CVSS17), which are approved and specifically designed to diagnose the symptoms of digital eye strain [34, 55, 61, 62]. However, subjective methods do not allow for the inclusion of current disorders of the visual organ of the subjects, which may contribute to the intensification of experienced symptoms [63].

Recently, a new questionnaire, the CVS-Smart, was developed. It is simpler to analyze than those mentioned above. This latest research instrument aims to improve the subjective diagnosis of CVS for patients and researchers, reducing dependence on objective ophthalmological examinations. As the only questionnaire, it covers all categories of symptoms (visual, eye-related, and extraocular), enabling a precise determination of the frequency of CVS occurrence and the classification of cases according to the level of probability – high, low, or absence of CVS [64, 65].

Digital eye strain can be recognized based on various indicators, related both to the function of the visual system and the condition of the ocular surface [22]. To objectively assess the condition of the visual organ in patients with suspected CVS, traditional and modern methods are used to examine: visual acuity, binocular vision and accommodation, the tear film (assessing, among other things, tear osmolality, evaporation rate, secretion, break-up time, and the state of the Meibomian glands) [19, 20, 40, 63], the critical flicker fusion frequency (CFF) [46], and the frequency and completeness of blinks using glasses or cameras [18, 19, 22, 26] with sensors that record eye fatigue in real-time.

Although objective ophthalmological examinations play an important role in confirming the diagnosis of CVS and excluding other conditions with similar symptoms, despite the existence of tools for assessing individual symptoms, there is still a lack of studies dedicated to the comprehensive diagnosis of CVS. Algorithms of artificial intelligence (AI), combined with augmented reality (AR) simulations, offer the potential to predict the risk of CVS and provide personalized diagnostic information for patients [19].

PREVENTIVE AND TREATMENT ACTIONS

Occupational health professionals play a key role, especially in the workplace, by disseminating knowledge among employees and supervisors regarding strategies for preventing and alleviating eye fatigue.

Treatment of CVS is multifaceted and based on alleviating symptoms, improving screen working conditions, and preventing the worsening of existing problems. A carefully taken patient history and thorough examination should reveal a correlation between VDT use and reported complaints. Unfortunately, conclusive methods for effectively treating the symptoms of CVS are still lacking.

Vision hygiene – the role of habits, environment, and family support

The use of electronic devices at nighttime should be limited, and exposure to blue light should be avoided to promote a normal sleep rhythm and allow adequate rest for the eyes [50, 66].

A proven method for preventing VDT-related issues is to encourage the public to diversify learning and work by using paper-based materials whenever possible. Prolonged reading of paper-based content under appropriate ergonomic conditions causes fewer symptoms of eye fatigue than reading on a digital display under comparable conditions [67].

To prevent CVS in children, parental involvement is crucial. Supporting children in finding hobbies and interests and encouraging interaction with peers helps reduce the risk of CVS by promoting a balanced lifestyle and limiting screen time.

Diet and supplements

Attempts have been made to determine which dietary factors reduce the effects of CVS. Due to the beneficial effects of omega-3 fatty acids in dry eye syndrome, their effects on the symptoms of VDTS, a related condition, have been investigated.

While individual randomized controlled trials have yielded divergent results, a study involving 3 months of supplementation with 360 mg of eicosapentaenoic acid (EPA) and 240 mg of docosahexaenoic acid (DHA) taken twice daily demonstrated a beneficial effect of oral omega-3 fatty acid supplementation on reducing tear evaporation rate and alleviating dry eye symptoms associated with CVS [68, 69].

Marine products are the richest natural sources of EPA and DHA. Omega-3 fatty acids are mainly found in oily fish, such as mackerel, salmon, and herring, and in plant-based sources like flaxseeds, nuts, chia seeds, and soybeans [70].

Lenses with a filter

The use of lenses that block a large portion of blue light is associated with a reduction in the number of reported symptoms related to eye fatigue and helps maintain the CFF index, which correlates with visual fatigue [46]. If the lenses were 100% effective, alleviating eye pain, itching, and the sensation of heaviness would be easier for individuals who cannot limit their use of display devices.

Unfortunately, numerous studies suggest a lack of compelling clinical evidence to support the claim that they improve visual function, sleep quality, reduce eye fatigue, or protect the macula in the general population [71–73].

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Refractive error correction

After long hours of working in front of a screen, difficulties with clearly seeing objects at various distances may arise. Regular eye examinations and the correction of uncorrected or improperly corrected refractive errors are fundamental elements in the prevention and treatment of CVS symptoms. These practices minimize the negative effects of prolonged screen work and improve visual comfort [8]. Selecting appropriate lenses should take into account the individual needs of the patient and the nature of their work – for example, whether it is performed mainly at close range or from a greater distance. Adjusting the power of the lenses to the distance of the screen reduces accommodative effort, which can improve visual comfort and reduce eye fatigue in individuals who spend many hours in front of a screen.

In the case of presbyopic individuals, the use of progressive addition lenses (PALs), although theoretically enabling vision correction at various distances, is often associated with subjective visual complaints. Studies indicate that over 70% of digital device users who wear PALs report experiencing vision problems [46, 55]. Furthermore, the use of PALs can lead to the adoption of a non-ergonomic body posture aimed at compensating for the viewing angle and distance to the screen, which negatively affects working comfort in the long run.

Ergonomics

The importance of ergonomics in the workplace is emphasized in numerous studies. Contrary to expectations, data analysis reveals a positive correlation between the level of knowledge about ergonomics and the frequency of reporting CVS symptoms within the studied group. This relationship may stem from a heightened awareness of risk factors among individuals whose professional activities involve prolonged exposure to monitors. However, the effectiveness of preventive interventions hinges on the practical implementation of ergonomic principles, which leads to a reduction in the occurrence of CVS symptoms among users of VDT devices [4].

Distance from the device and viewing angle

The distance at which digital devices are used constitutes a significant risk factor for the onset of visual discomfort. The closer the screen is to the eyes, the greater the effort required to maintain adequate visual acuity.

Research indicates that shortening the distance between the eyes and the screen results in a more pronounced intensification of eye fatigue symptoms. A monitor height adjusted to position the upper edge of the screen below eye level alleviates discomfort and eye fatigue associated with its use [16]. The American Optometric Association recommends that the monitor be positioned 10–12.5 cm below eye level and at a distance of 50–70 cm from the eyes.

Preventing glare

Positioning the computer screen to avoid glare from overhead lighting or windows is crucial [6]. Furthermore, the use of screen filters is recommended to help reduce moni-

TABLE 2

Minimum health and safety requirements for workstations with display screen equipment according to European Union directives [80].

Equipment	Environment
General The equipment must not pose any hazard to the user.	*General* The workstation must provide the user with sufficient space for free movement and posture changes.
Screen The screen must provide a clear, stable image without flickering. Brightness and contrast should be easy to adjust. The monitor must allow for position adjustment and be free from glare. The use of a stand or adjustable desk is permitted.	*Lighting* General and task lighting should ensure appropriate contrast and visual comfort suited to the type of work. Glare should be avoided through proper positioning of light sources.
Keyboard The keyboard should be separate from the monitor and allow for an ergonomic working position. The space in front of it must support the hands. The keyboard surface should be matte, and key markings should be clear and easy to read.	*Reflections and glare* The workstation design should eliminate glare from windows, walls, and other light sources. Windows should be equipped with adjustable blinds.
Desk or work surface The work surface should be large enough, matte, and allow flexible equipment placement. The document holder must be stable and adjustable. The worker should have enough space to maintain a comfortable position.	*Noise* The noise level generated by equipment should be taken into account so as not to interfere with work or communication.
Chair The chair must be stable and allow freedom of movement. The seat and backrest height should be adjustable. A footrest should be available upon request.	*Temperature* The equipment must not emit excessive heat that could cause discomfort.
	Radiation Radiation levels (other than visible light) must be limited to a safe minimum.
	Humidity An appropriate humidity level should be maintained in the workplace.

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tor glare, thereby minimizing the negative effects of excessive light reflected from the screen [4, 74].

Adjusting settings in devices with a screen

Available publications reveal various attempts to minimize the effects of exposure to blue light emitted by the screens of digital devices. These attempts include implementing a dark/night mode (displaying bright text on a dark background) or a night shift mode (to shift the spectrum of light emitted from digital device screens toward longer wavelengths and warmer colors) in VDTS.

However, only limited research assessing the effectiveness of these strategies exists, and this research fails to provide definitive answers [75].

Breaks during work

Adherence to the 20–20–20 rule, which entails taking regular 20-second breaks from visual work in front of a monitor every 20 min to focus on an object at least 6 m (20 feet) away, does not yield conclusive therapeutic effects, as confirmed by the conflicting results of existing studies [76].

It has been demonstrated that taking regular breaks from display devices contributes to an increased blinking frequency and reduces the risk of digital eye strain [77]. Nevertheless, the current body of knowledge does not allow for the establishment of clear guidelines regarding the optimal regularity and duration of breaks. Further analyses are therefore necessary to enable the standardization of recommendations pertaining to this form of prevention.

Potential treatment methods

Despite promising results reported in meta-analyses, proposed treatments for CVS, including artificial tears, topical secretagogues [78], heated moisturizing masks, carotenoid supplementation [79], or supplements containing blueberry or bilberry extract, lack sufficient scientific evidence to permit a thorough evaluation of their effectiveness.

CONCLUSIONS

CVS presents a growing public health challenge, with its increasing prevalence among younger patients reflecting an inadequate level of education and a lack of widespread awareness regarding ergonomics and the proper use of digital devices.

Due to the absence of universally accepted diagnostic criteria, current clinical management of VTDS relies heavily on the patient's subjective experiences and reported symptoms of visual strain from screen device use.

Regular eye examinations, particularly for individuals who intensively use display devices, are crucial for early detection of ocular abnormalities that may contribute to the development or intensification of CVS.

Raising awareness among healthcare professionals and the public can help reduce misdiagnoses, thereby limiting unnecessary pharmacological treatment and medical interventions. Therefore, it is essential to develop and implement comprehensive, targeted educational programs that incorporate both preventative measures and the fundamentals of ergonomic practices for digital device use.

In light of these considerations, intensifying research efforts to better understand the pathophysiological mechanisms underlying VTDS is critical. This will facilitate the improvement of existing therapies and the development of novel, effective strategies to enhance visual comfort and increase productivity in computer-based work environments.

Future research should focus on developing and validating standardized diagnostic criteria for CVS, utilizing objective and repeatable diagnostic tools, and conducting detailed analyses of the correlations between specific symptoms and the duration of exposure to screen devices. Ultimately, investing in visual health during this era of digital transformation will not only improve individual well-being but also enhance professional effectiveness and overall quality of life.

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