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REVIEW

Digital Eye Strain- A Comprehensive Review

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ABSTRACT

Digital eye strain (DES) is an entity encompassing visual and ocular symptoms arising due to the prolonged use of digital electronic devices. It is characterized by dry eyes, itching, foreign body sensation, watering, blurring of vision, and headache. Non-ocular symp-

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toms associated with eye strain include stiff neck, general fatigue, headache, and backache. A variable prevalence ranging from 5 to 65% has been reported in the pre-COVID-19 era. With lockdown restrictions during the pandemic, outdoor activities were restricted for all age groups, and digital learning became the norm for almost 2 years. While the DES prevalence amongst children alone rose to 50–60%, the symptoms expanded to include recent onset esotropia and vergence abnormalities as part of the DES spectrum. New-onset myopia and increased progression of existing myopia became one of the most significant ocular health complications. Management options for DES include following correct ergonomics like reducing average daily screen time, frequent blinking, improving lighting, minimizing glare, taking regular breaks from the screen, changing focus to distance object intermittently, and following the 20-20-20 rule to reduce eye strain. Innovations in this field include high-resolution screens, inbuilt antireflective coating, matte-finished glass, edge-to-edge displays, and image smoothening graphic effects. Further explorations should focus on recommendations for digital screen optimization, novel spectacle lens technologies, and inbuilt filters to optimize visual comfort. A paradigm shift is required in our understanding of looking at DES from an etiological perspective, so that customized solutions can be explored accordingly. The aim of this review article is to understand the pathophysiology of varied manifestations, predisposing risk factors, varied management options, along with changing patterns of DES prevalence post COVID-19.

Keywords: Accommodation; Convergence; COVID-19; Digital eye strain; Digital revolution; Online classes; Pre-COVID-19 era; Smartphone

Key Summary Points

Digital eye strain has been an emerging health care problem in recent times.

Online education and work from home have become the new norms since the beginning of the COVID-19 pandemic.

DES symptoms can be broadly divided into ocular surface-related symptoms like irritation/burning eyes, dry eyes, eyestrain, headache, tired eyes, sensitivity to bright lights, and eye discomfort. Accommodation-related symptoms include blurred near or distance vision after computer use and difficulty refocusing from one distance to another.

Recommendations to alleviate DES include the correct ergonomic use of digital devices, limiting daily screen time to $\leq$ 4 h, frequent breaks, screen time tracking, blue-light filtering glasses with antireflective coating, and an inclination towards outdoor recreational activities.

INTRODUCTION

Technology has transformed every realm of our lives in the information age, from healthcare to education. The digital revolution, or the third industrial revolution, commenced in the 1980s, showing no signs of deceleration. Prompt communication, extensive availability of information, and most imperative, going paperless or GO GREEN are various advantages. However, every action comes with its opposite reaction, and the digital revolution is no deviation from this rule. As outlined by the American Optometric association, digital eye strain encompasses a cluster of ocular and vision-related problems attributed to prolonged usage of desktops, laptops, mobile phones, tablets, e-readers, and storage devices [1].

The Digital Eye Strain Report of 2016, which included survey responses from over 10,000 adults from the USA, identified an overall self-reported prevalence of 65%, with females more commonly affected than males (69% vs. 60% prevalence) [2]. Its pathophysiology is multifactorial, with several contributing factors being reduced contrast level of letters compared to the background of digital screens, screen glare and reflections, wrong distance and angle of viewing digital screens, poor lighting conditions, improper posture during usage, and infrequent blinking of eyes [3]. The eye focusing and ocular movements required for better visibility of digital screen place additional demand on an intricate balance between accommodation and convergence mechanisms, thus making people with uncorrected or under-corrected refractive errors even more susceptible [4]. The condition can cause an array of symptoms, including eyestrain, watering of eyes, headache, tired eyes, burning sensation, red eyes, irritation, dry eye, foreign body sensation, blurred vision at near, and double vision [5].

According to the American Optometric Association, the usage of digital devices continuously for two hours is adequate to bring about digital eye strain [1, 6]. However, during the recent outbreak of novel Coronavirus disease-19 (COVID-19) declared by World Health Organization, there has been an upsurge in the usage of digital devices. Several countries worldwide declared a nationwide lockdown to shut down activities that necessitate human assembly and interactions, including educational institutions, malls, religious places, offices, airports, and railway stations, to contain the spread of the virus [7]. A major part of the world was compelled to be confined indoors due to the dreaded consequences of this global pandemic, and its effects could be visualized in various sectors. Due to the lockdown, most people resorted to the internet and internet-based services to communicate, interact, and continue with their job responsibilities from home. Working from home became the new norm of working for millions of employees worldwide. Video-conferencing became the new mode of holding meetings and conferences.

Education is yet another domain that witnessed a change in paradigm to the online way of implementation. Online learning services served as a panacea during the pandemic. Video conferencing platforms like Zoom and Google Meet have been used by schools, colleges, and universities worldwide since the beginning of the lockdown. There was a rise in usage of internet services from 40 to 100%, compared to pre-lockdown levels [8]. Digital payments and digital currencies played a vital role in the pandemic. Being restricted indoors, digital devices became the only source of entertainment. Thus, the COVID-19 pandemic has added even more fuel to the already existing fire of the digital revolution. Ultimately this has resulted in an upsurge in the symptoms of digital eye strain amongst most individuals irrespective of age, sex, race, or region. The objective of this review article is to comprehensively present an overview of digital eye strain, its pathophysiology, management strategies, role of ophthalmologists and visual health specialists in educating parents or patients and also to understand the impact of COVID-19 on DES prevalence. We have also briefly highlighted the future research prospects in the field of DES. This review article is based on previously conducted studies. The article does not contain any studies with human participants or animals performed by any of the authors.

Literature Search

A comprehensive systematic literature search was done using PubMed, Google Scholar, and Cochrane database. The search was done using the terms "digital eye strain" or "computer vision syndrome" or "ocular asthenopia secondary to digital devices" or "eye strain", or "visual fatigue" or "blue-blocking glasses" on May 15, 2022. All the articles with available abstracts along with the referenced articles until the date of search were evaluated. Original research work in the English language on DES and those mentioning prevalence, risk factors, clinical features were considered for inclusion into the present review article. The final reference list was generated on the basis of original

Table 1 Published studies that explored role of blue-blocking filters on digital eye strain

Authors, Journal, Year, and Place	Study participants	Methodology	Results	Conclusion
Vera J et al. Clin Exp Optom. 2022 Jan 20:1–6 [23] Spain	Twenty-three healthy young adults, mean age 22.9 ± 3.2 years	Two reading tasks from computer screen with or without blue-blocking filter on two different days. Orbicularis oculi (OO) muscle activity recorded by surface electromyography and DES symptoms noted during 30-min reading task	No change in orbicularis oculi muscle activity with or without using blue-blocking filter. Reading increased visual fatigue and discomfort but reduced activation levels	Neither the orbicularis oculi muscle activity nor the visual symptoms altered significantly during 30-min reading task with blue-blocking filters
Rosenfield M et al. Work. 2020;65(2):343–348 [24] United States	Twenty-four subjects	20-min reading task from a tablet computer after wearing either blue-blocking filter lens (TheraBlue 1.67 or TheraBlue polycarbonate) or a CR-39 control lens	An increase in symptoms was observed immediately after near vision task ($p = 0.00001$), no significant difference in symptoms was found between the lenses ($p = 0.74$)	Use of blue-blocking filters as a treatment for DES is not well proven. Optimal environment for screen viewing, are more likely to benefit in minimizing symptoms
Redondo B et al. Ophthalmic Physiol Opt. 2020 Nov;40(6):790–800 [25] Spain	Nineteen healthy young adults, mean age 22.0 ± 2.7 years	30-min two reading tasks on computer screen placed at 50 cm, with either commercially available blue-blocking filter or without any filter on two different days	Blue light levels had no effect on lag and variability of accommodation ($p = 0.34$ and 0.62, respectively) Blue-blocking filter was associated with improved reading speed of 16.5 words per minute ($p = 0.02$). There was no significant change in pupil dynamics or perceived levels of visual discomfort	Blue-blocking filter had no effect on accommodation dynamics or visual symptoms related to DES

Table 1 continued

Authors, Journal, Year, and Place	Study participants	Methodology	Results	Conclusion
Palavets T et al. Optom Vis Sci. 2019 Jan;96(1):48–54 [26] United States	Twenty-three young, visually normal subjects	30-min reading task from tablet, with either blue-blocking (BB) or neutral-density (ND) filter producing equal screen luminance. Questionnaire to quantify DES symptoms	Mean total DES symptom scores for BB and ND filters were 42.83 and 42.61, respectively. Between two filters, no significant differences were found between accommodation and vertical palpebral aperture	Use of blue-blocking filters to minimize near work-induced asthenopia has limited proven evidence

work considered for inclusion relevant to the broad scope of this review article. Studies done before and after the COVID-19 pandemic have been summarized in tabular formats.

SYMPTOMS OF DES

Digital eye strain has been used synonymously with ocular asthenopia secondary to digital devices, computer vision syndrome, eye strain post computer or mobile usage, or even visual fatigue [3, 9–12]. The most common symptom is a sense of eye discomfort. This may be in the form of watering, redness, and itching in the eyes. The patients may complain of dryness in the eyes.

Apart from this, a frequent complaint is blurry vision. The patient typically complains of blur and clear vision episodes, and eye strain. This usually reduces their concentration but improves after rest. Another set of symptoms is that the patient complains of glare, excessive sensitivity to light, and inability to keep the eyes open. All of these may be associated with headaches and occasionally sore neck or back [3, 10–13].

Broadly, these symptoms can be classified into three categories:

a. Ocular surface-related symptoms are secondary to reduced blink and related to dry eye. These symptoms typically include irritation/burning eyes, dry eyes, eye strain, headache, tired eyes, sensitivity to bright light, and eye discomfort [13, 14].
b. Accommodation or vergence-related symptoms are secondary to excessive work and related to anomalies of accommodation or binocular visual system. These symptoms include blurred near or distance vision after computer use, difficulty refocusing from one distance to another, or diplopia [13–15].
c. Extraocular symptoms include musculoskeletal symptoms which can result in inconvenience in daily routine activities. These may include body discomfort like headache, neck or shoulder pain, and back pain [16].

Now, even myopia progression has been linked to the digital eye strain in children. This would remain unique to the pediatric population only [17]. At this point, there is sufficient evidence to suggest that this may be linked, but it would need further work to cement its place in the syndrome complex of digital eye strain.

Table 2 Summary of research work published on digital eye strain prior to the COVID-19 pandemic

S. no.	Authors and Country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
1	Sancho et al. Int J Environ Res Public Health, 2022 Apr 8;19(8):4506 [38] Spain	241 subjects, 64.3% women, Mean age, 45.49 ± 10.96 years (18–65 years age group)	Amblyopia, dry eyes, retinal pathologies, occupational use of digital devices (DD), number of hours and years of DD use, scheduled break	Burning, itching, foreign body sensation, eye blinking, redness, pain, tearing, heaviness, dryness, blurred vision, double vision, etc.	TBUT, Schirmer's test, Rasch–Andrich Rating Scale Model Analysis, Italian Version of the Computer Vision Syndrome Questionnaire (CVS-Q IT©)	Prevalence of CVS was 67.2%, blurred vison-63.5%, worsening of sight, 62.3%, headache 56%. Least prevalent eye strain-11.2%, colored halos-16.2% and double vision-17.4%	CVS-Q IT© is a simple, reliable, and valuable tool for assessing CVS in adults
2	Auffret et al. J Fr Ophtalmol 2022 Apr;45(4):438–445 [39] France	52 participants	Chronic exposure to digital devices	Ocular discomfort, blurred vision, photophobia	Short-term screen exposure, chronic screen exposure, ocular discomfort questionnaire refraction, phoria, near point of accommodation and convergence, fusional vergence and binocular amplitude facility	No significant difference between control group and exposed group in any objective parameters Exposed group have high discomfort score for near (p-0.04), intermediate (p-0.02) blurred vision and light sensitivity (p-0.04)	Binocular balance is affected by chronic and intensive screen use

Table 2 continued

S. no.	Authors and Country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
3	Moore et al. Ophthalmic Physiol Opt, 2021 Nov;41(6):1165–1175 [40] United Kingdom	406 respondents	Digital device use		Anonymous online questionnaire, covering attitude and understanding of DES	Estimations of the proportion of patients affected by DES were lower than reports in the literature (median 25%, IQR 10-50%). Most respondents always (60.6%) or frequently (21.9%) inquired about device usage in routine case history taking, and also asked follow-up questions, although 29.3% only asked about the presence of symptoms half the time or less	DES causes frequent and persistent symptoms, and practitioners reported high levels of confidence in discussing DES, patients can expect to receive advice on symptoms and management from their optometrist
4	Zayed HAM et al. Environ Sci Pollut Res Int. 2021 May;28(20):25187–25195 [41] Egypt	108 IT professionals	Female gender, age $\geq$ 35 years, computer use > 6 h/day, refractive error, not adjusting workstation ergonomics, no breaks during computer work, dry environment	Headache (81.5%), burning of eyes (75.9%), and blurred vision (70.4%)	Computer vision syndrome questionnaire (CVS-Q)	Prevalence of DES was found to be 82.41%	DES can be prevented by increasing knowledge and awareness about eye health, proper ergonomic computer training, and suitable comfortable workplace environment

Table 2 continued

S. no.	Authors and Country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
5	Meyer D et al. Cont Lens Anterior Eye. 2021 Feb;44(1):42–50 [42] United States	Six hundred and two soft contact lens (SCL) wearers and 127 non-contact lens (non-CL) wearers using digital devices at least 4 h per day		Primary sensations eye strain/pain, soreness, tired eyes, and headaches Secondary or surface sensations burning, eye irritation, tearing and dryness Visual sensations blurred/double vision and words move/float	Questionnaire assessing frequency and severity of 10 common symptoms associated with eye fatigue related to DES	89% of SCL wearers reported eye fatigue more than once per month, and > 60% reported more than once per week Dryness and irritation were more common among SCL wearers	Eye fatigue is highly common among both soft contact lens and non-contact lens wearers. The frequency or severity is same among SCL users and other group
6	Al Dandan O etal, Acad Radiol. 2021 Aug;28(8):1142–1148 [43] Saudi Arabia	198 radiologists (111 males and 87 females), including 40.9% residents, 27.3% senior registrars, and 27.3% consultants	Female sex and taking breaks once or twice a day only		Online survey	26.8% underwent an eye examination within past one year and 50.5% experienced DES	DES is common among radiologists. It is more common among radiology residents, females, and those not taking frequent breaks

Table 2 continued

S. no.	Authors and Country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
7	Ichhpujani P et al. BMC Ophthalmol. 2019 Mar 12;19(1):76 [35] India	576 adolescents attending urban schools	Preference to lie down		Surveyed regarding their electronic device usage	18% (103) experienced eyestrain at the end of the day 18% experienced symptoms related to DES. 20% students aged 11 years use digital devices on daily basis, in comparison with 50% aged 17. In addition to homework aids, one-third of the participants reported using digital devices for reading instead of conventional textbooks. 77% students prefer sitting on a chair while reading, 21% prefer to lie on bed and 2% students alternating between chair and bed	The increased use of digital devices by adolescents brings a new challenge of digital eyestrain at an early age

PATHOPHYSIOLOGY OF DES

The symptoms experienced in computer vision syndrome are caused by three potential mechanisms: (i) Extraocular mechanism, (ii) accommodative mechanism, (iii) ocular surface mechanism [18].

Extraocular mechanisms not specifically linked with ocular usage may cause musculoskeletal symptoms such as neck stiffness, neck pain, headache, backache, and shoulder pain [16]. These symptoms are associated with postural problems secondary to improper placement of computer screens, unsuitable table or chair height, or incorrect distance between the eye and screen resulting in unnecessary stretching or forward bending often resulting in a muscular sprain [19, 20].

Accommodative mechanisms cause blurred vision, double vision, presbyopia, myopia, and slowness of focus change [13, 14, 18]. Changes in accommodation lag have been noted secondary to digital device usage over prolonged periods [21]. However, the effects on accommodation, convergence, and pupillary size are mainly due to the demanding near work and not per se due to the screen [21]. The effect of blue light on visual health has also been studied in detail. However, at this point, there is a lack of consensus in the findings of these studies to address the health effects of blue-blocking spectacle lenses [22]. Table 1 summarizes results from research work done on blue-blocking glasses.

An ocular surface mechanism causes symptoms such as dryness of the eyes, redness, gritty sensation, and burning after an extended period of computer usage. Eyeblink helps maintain a normal ocular surface through a whole cycle of secretion of tears, wetting of ocular surface, evaporation, and finally, drainage of tears [27]. It is now well known that the blink rate reduces significantly during computer usage from 18.4 to 3.6/min in one of the studies and from 22 to 7 blinks/min in another study [28, 29].

The pathophysiology of reduced blink and squinting is bimodal; one, it increases the visual acuity in the presence of a refractive error and decreases the retinal illumination when using a source with glare in the superior visual field, as reported by Sheedy et al. [30]. Rather than the reduced blink rate, an incomplete blink, where the upper eyelid does not cover the entire corneal surface, may be more relevant to dry eye as the tear film stability can be maintained with a reduced blink rate, provided that most blinks are complete [31].

Apart from this, increased surface of cornea exposure caused by horizontal gaze at the computer screen and reduction of tear production due to the aging process and contact lens usage may also increase the digital eye strain.

BURDEN OF DES AND ASSOCIATED CONDITIONS

There has been massive growth in digital device usage in the past decade, hence increasing the risk of DES. There has been a surge of mobile devices in individuals across all age groups, with more elderly populations also reported to be engaged with digital media [3]. A report by the Vision Council in 2016 noted that in the USA, approximately two-thirds of adults aged 30–49 years spend five or more hours on digital devices [2]. The rampant use of social media is particularly pronounced among younger adults, with reportedly 87% of individuals between 20 and 29 years of age reporting the use of two or more digital devices simultaneously [2]. The burden of DES is challenging to measure because of the variability in symptoms reported across the literature. The computer-related symptoms could be due to accommodation anomalies (such as blurred near vision, blurred distance vision, and difficulty refocusing after prolonged computer work) and those that seemed linked to dry eye (dry eyes, eyestrain, headache, burning eyes, sensitivity to bright lights, and ocular discomfort). Before the COVID-19 pandemic, a highly variable prevalence of DES symptoms ranging from 5 to 65% have been reported [2, 14, 32, 33]. Most of the studies reported dry eyes and accommodation anomalies as the presentation of DES, with refractive error, squinting, and blinking being studied less commonly. The data inconsistency was because these studies were either done

Table 3 Review of literature of digital eye strain during the COVID-19 pandemic

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
1	Wangsan et al. Int J Environ Res Public Health. 2022 Apr; 19(7): 3996 [53] Thailand	527 students, 70.40% females, mean age 20.04 ± 2.17 years	Female gender, atopic eye disease, dry eyes, itching, red eye, eye pain, astigmatism, previous refractive surgery, tear substitute use, contact lens use, mobile and tablet use	Eye pain-96.5%, burning sensation-92.5%, headache 90.08%, defective vision-15.95	CVS-Questionnaire (CVS-Q), CVS was diagnosed with a score of CVS-Q $\geq$ 6	Prevalence of CVS was 81%, distance less than 20 cm (52.7 vs. 40%), less brightness less 14.8 vs. 7.0%) and glare or reflection on display (47.8 vs. 29.0%) were associated with CVS	Social distancing is mandatory, online classes are unavoidable, increased screen was associated with increases prevalence of CVS. Laptop/desktop should be preferred over mobile phone
2	Cai et al. Front Med (Lausanne), 2022 Mar 21;9:853293 [54] China	115 children with myopia	Strict home confinement, hereditary, closed indoor work time, excess exposure to electronic gadgets Protective factors- age, rest time, sleep time, and distance from the device while usage	Asthenopic symptoms	Axial length assessment (IOL Master 700) and refractive errors (without cycloplegia), visual function, convergence insufficiency symptom survey (CISS) and eye care habits questionnaire	Axial length elongation was 35% higher than normal, positively correlated with severe asthenopia (r = 0.711), negative with age (r = − 0.442), distance from eyes (− 0.238)	Decreased outdoor activities and increased screen time accelerated myopia progression by 1/3
3	Demirayak et al. Indian J Ophthalmol 2022 Mar;70(3):988–992 [45] Turkey	692 children under the age of 18 years, mean age 9.72 ± 3.02 years, 360 (52%) were girls, 62.57% were students in primary school	Computer use (61.7%), smartphones (57.8%), mean duration of display device use 71.1 ± 36.02 min	Headache (52.2%), eye fatigue (49.3%), and eye redness (49.3%) and double vision-8.8%	Online electronic survey using Google Forms	48.2% experienced 3 or more symptom, male gender and age were independent risk factors for 3 or more symptoms	Digital device use during the pandemic exacerbated the DES among children
4	Basnet et al. JNMA J Nepal Med Assoc, 2022 Jan 15;60(245):22–25 [55] Nepal	318 subjects	Digital device use, tablet use, computer, and smartphone	Eye strain-199 (62.6%), tiredness of eyes-162 (50.9%)		Prevalence of DES was found to be 94.3%	Prevalence of DES has increased during COVID-19 pandemic

Table 3 continued

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
5	Regmi A et al. Clin Exp Optom. 2022 Feb 14:1–7 [56] India	1302 participants	Females spending more than 6 h on digital devices, taking breaks from digital devices after 2 h, inability to maintain a fair sleep schedule, and inability to make ergonomic modifications at home		Electronic communication sources using Google Forms	94.5% had one or more visual and ocular symptoms associated with digital devices usage. 43.1% reported that these symptoms began post-lockdown	A high prevalence of visual/ocular symptoms (43.1%) and work-related musculoskeletal disorder (45%) were reported during COVID-19 lockdown
6	Mohan A et al. Indian J Ophthalmol. 2022 Jan;70(1):241–245 [17] India	133 children (266 eyes)	History of rapid progression in pre-COVID-19 era ($p = 0.002$) and sun exposure < 1 h/day ($p < 0.00001$)			Annual myopia progression was found to be statistically significant during COVID-19 as compared with pre-COVID-19 (0.90 vs. 0.25 D, $p < 0.00001$). A total of 45.9% of children showed an annual progression of $\geq$ 1 D during the pandemic as compared with 10.5% before the COVID-19 ($p < 0.00001$)	Rapid myopia progression in children during current pandemic and children should be provided with socially distant outdoor activities to increase their sun exposure and diminish the rate of myopia progression
7	Kaur K, J Pediatr Ophthalmol Strabismus. 2021 Dec 20:1–12 [46] India	305 responses	Digital device use	Headache was the most common complaint in 100 children (51% of total symptomatic), followed by ocular pain in 19 children (9.64% of total symptomatic)	Online questionnaire using Google Forms	Prevalence of DES was found to be 64.6%	There is a strong need to bridge this knowledge gap and prevent the increased prevalence of myopia and digital eye strain in the future

Table 3 continued

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
8	Gupta R et al. J Curr Ophthalmol. 2021 Jul 5;33(2):158–164 [57] India	654 students, mean age: 12.02 ± 3.9 years, 332 (58%) females	Spectacle users, age, and duration of digital device	Redness (69.1%), heaviness of eyelids (79.7%), blinking (57.8%), blurred vision (56.9%), light sensitivity (56%)	Rasch-based Computer-Vision Symptom Scale was deployed to measure the DES	Mean CVS score of. class 1–5 was 26.1 ± 7.8, class 6–9 was 24.8 ± 6.6, class 10–12 was 29.1 ± 7.1. Mean CVS score was lowest in < 4 h group followed by 4–6 h and then > 6 h	The majority experienced at least one symptom of DES. There is a need to educate the masses about measures to prevent DES
9	Mohan A, et al. J Pediatr Ophthalmol Strabismus. 2021 Jul-Aug;58(4):224–231 [48] India	46 children; mean age of 14.47 ± 1.95 years	Digital devices for 4 h/day or more		Convergence Insufficiency Symptom Survey (CISS) questionnaire	Mean CISS scores were 21.73 ± 12.81 for digital device use < 4 h/day and 30.34 ± 13.0 for ≥ 4 h/day (p = 0.019). Mean near exophoria (p = 0.03), negative fusional vergence (p = 0.02), negative relative accommodation (p = 0.057), and accommodation amplitude (p = 0.002) were different between the two groups	Online classes for more than 4 h resulted in abnormal binocular vergence and accommodation

Table 3 continued

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
10	Mohan A et al. Strabismus. 2021 Sep;29(3):163–167 [47] India	8 children, mean age 12.5 ± 4.2 years, all 8 males	Emmetropia (5), myopia (1), pseudomyopia (1), hyperopia (1)		Diplopia, Hess chart, visual acuity by Snellen chart, alternate prism cover test, cycloplegic retinoscopy, neurological examination	Mean duration of smartphone use 4.6 ± 0.7 h, children attending classes for > 4 h/day. The angle of deviation for near and distance were 48.1 ± 16.4 PD and 49.3 ± 15.9 PD, respectively, with normal ocular motility	Prolonged near work especially using smart phone for e-learning might lead to AACE in children
11	Salinas-Toro D et al. Int J Occup Saf Ergon. 2021 Jul 7:1–6 [58] United States	1797 respondents; mean age of respondents 40.5 ± 11.1 years, and 69.9% were female	Female gender, refractive surgery, rosacea, depression, previous dry eye disease, keratoconus, blepharitis, occupation, contact lens use	Soreness, pain, foreign body sensation, redness, visual fatigue, redness and blurred vision	Ocular symptom index, DED (dry eye questionnaire 5 [DEQ-5] questionnaire	The mean number of teleworking weeks was 10.2 ± 3.0. All DES symptoms presented a significant increase ($p < 0.001$). The mean DEQ-5 score was 8.3 (*SD* 4.9). Women had a higher score ($p < 0.001$)	Visual display terminal hours are related to increase in DES symptoms and high prevalence of DED
12	Zheng et al. J Med Internet Res, 2021 Apr 30; 23 (4): e 24316 [59] China, Singapore, Ireland, and Australia	1009 children, 2 groups – interventional group (485)—exercises and ocular relaxation, and access to a digital behavior change intervention, or control group (469)—health education information only Mean age 13.5 ± 0.5 years, 499 males	Smartphone use, gender, use of glasses, parental education, smoking and family history	Eye strain, anxiety, sleep disturbance,	Health education information promoting exercise and ocular relaxation, and access to a digital behavior change intervention, with live streaming and peer sharing of promoted activities	Mean anxiety score in the intervention group was greater (− 0.23) as compared to the control group (0.12). A significant reduction in eye strain was observed in the intervention group (− 0.08) as compared to controls (0.07)	Digital behavior change reduced anxiety and eye strain among children

Table 3 continued

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
13	Gammoh Y. Cureus. 2021 Feb 26;13(2):e13575 [60] Jordan	382 students, mean age of participants was 21.5 years (± 1.834), male:female ratio was 1:1.56	Digital device use for > 6 h per day	Tearing (59%), headache (53%), and increase sensitivity to light (51%)	Computer Vision Syndrome Questionnaire (CVS-Q)	The prevalence of CVS was found to be 94.5%. Tearing was most common-(59%), double vision was least common among students-18.3%. DD use for > 6 h/ day was present in 55.5% patients, and 30.7% of reported pain in joints of fingers and wrists after using a mobile phone	CVS is highly prevalent among Jordan university students. Safe habits in digital device use are recommended to prevent DES
14	Alabdulkader B. Clin Exp Optom. 2021 Aug;104(6):698–704 [49] Saudi Arabia	1939 participants, mean age was 33 ± 12.2 years and 72% were women	Digital device use duration, use of multiple devices, age, optical correction, and status of employment		Self-reported questionnaire	Incidence of digital eye strain was 78%	Importance of regular eye examination, limiting screen time, the 20–20-20 rule, and the use of lubricating drops to help reduce the symptoms of DES should be emphasized
15	Ganne P et al. Ophthalmic Epidemiol. 2021 Aug;28(4):285–292 [61] India	941 responses from online classes students (688), online classes teachers (45), and the general population (208)	Students attending online classes, those with eye diseases, greater screen time, screen distance < 20 cm, using gadgets in dark and infrequent/no breaks		Pre-validated questionnaire	DES prevalence was higher among students taking online classes (50.6%) compared to the general public (33.2%). An increase in screen time has been observed during the pandemic compared to pre-pandemic time	There is a need to educate about ergonomics of screen usage. There is need to reduce the online classes duration and working hours for professionals to control the epidemic of DES

Table 3 continued

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
16	Mohan A et al. Indian J Ophthalmol. 2021 Jan;69(1):140–144 [44] India	217 parents, mean age 13 ± 2.45 years	Age > 14 years, male gender, smartphone use, > 5 h of digital device use and > 1 h/day of mobile games		Online electronic survey—Computer Vision Syndrome Questionnaire	Mean digital device use duration during COVID era (3.9 ± 1.9 h) is more than pre COVID era (1.9 ± 1.1 h). 36.9% used digital devices > 5 h in COVID era as compared to 1.8% pre COVID era. Smartphones were most common digital device used (61.7%). 49.8% attended online classes for > 2 h per day	DES prevalence increased among children in COVID era. Duration, type, and digital device distance ergonomics can avoid DES in children

Table 3 continued

S. no.	Authors and country	Demographics	Risk factors	Clinical features	Investigations	Outcome	Conclusion
17	Bahkir FA et al. Indian J Ophthalmol. 2020 Nov;68(11):2378–2383 [62] India	407 responses, mean age was 27.4 years, 55.5% were males and 44.5% were female	Female gender, student population	Headache, eye pain, heaviness of eyelids, redness, watering, burning sensation, dryness, increased light sensitivity, itching, excessive blinking, difficulty in focusing printed text, blurred vision, foreign body sensation, double vision	Open online survey through social media platforms	93.6% respondents reported increased screen time after lockdown. An average increase of 4.8 ± 2.8 h per day was reported. Total daily usage was found to be 8.65 ± 3.74 h. 62.4% reported sleep disturbances. 95.8% experienced at least one symptom related to DES, and 56.5% agreed to increased frequency and intensity of symptoms post lockdown	Awareness should be created about prevention of DES, and additional measures should be explored to control the adverse effects related to digital devices

through self-reported questionnaires, with variable definitions of DES being used and very little literature reporting the objectively determined DES [3]. Another shortcoming of the older (before COVID-19) studies is that the occurrence of DES amongst children was understudied [34–37]. In children, the prevalence of asthenopia due to presumed DES was about 20% before the pandemic [35]. The COVID-19 pandemic has increased our awareness of the DES and shed more light on the actual disease burden of DES, more so in the younger population. Table 2 summarizes the research work conducted prior to the COVID-19 pandemic.

With the lockdown restrictions during the COVID-19 pandemic, outdoor activities were restricted for all age groups, and digital learning became the norm for almost 2 years. Hence, digital device usage increased throughout the world, exacerbating DES symptoms. DES prevalence amongst children alone rose to 50–60% in the COVID-19 era [44–46]. In children, the symptoms expanded to include recent onset esotropia and vergence abnormalities as part of the DES spectrum [47, 48]. Overall, the incidence of DES was 78%, with participants reporting one or more DES-related symptoms [49]. This was primarily due to the overall time spent on digital devices (7–10 h/day) during the lockdown period, significantly greater than during the pre-curfew period (3–5 h) in all studies [49, 50]. The virtual classes for children and "work from home policy" in office-going adults necessitated additional usage of digital devices. One of the most significant ocular health complications of the COVID-19 pandemic has been new-onset myopia and the increased progression of existing myopia due to excessive near work [17, 50, 51]. The prevalence of myopia has been nearly 50% in the COVID era, with accelerated progression from 0.3D in pre-COVID to 1D in the COVID era [52]. This influence on myopic progression has been maximum in the age group of 6–8 years [51]. Table 3 summarizes the findings from research work done during COVID-19 era. With time, we might have further studies detailing the increase in DES burden due to home confinement in COVID.

MANAGEMENT STRATEGIES

Digital screen-time refers to time spent in front of a screen, such as watching television, working on a computer, laptop, or tablet, using a smartphone, and playing video games. It is a sedentary lifestyle habit with excessive visual activity, which has implications both on ocular and general health hygiene [63]. Owing to home confinement during the COVID-19 pandemic, there has been a substantial rise in usage of the digital platform for work and education. As a result of the lack of outdoor activities and social interaction, people have resorted to television and social media for entertainment with an unintentionally increased dependence on these devices [64, 65]. Wong et al. have rightly pointed out that the behavioral changes arising from this growing dependence may persist even after the COVID-19 pandemic [66].

The American Optometric Association has defined digital eye strain (DES) as an entity encompassing visual and ocular symptoms arising from the prolonged use of digital electronic devices [1, 67]. It is characterized by symptoms such as dry eyes, itching, foreign body sensation, watering, blurring of vision, and headaches [3]. The prevalence of DES reported in the literature ranges from 25 to 93% [68–71] and a recent meta-analysis of available data linked to asthenopia associated with DES reported a pooled prevalence of 19.7% in the pediatric population [34].

Continuous staring at the screen leads to a decrease in the blink rate, causing dry eye-related problems. Smartphone use is more commonly associated with dry eye disease than other digital devices [72]. In a case–control study among school-going children, Moon et al. reported an association of 71% among smartphone users [39]. They also documented that symptoms of dry eye diseases were higher in the children above the age of 14 years than in the younger age group. This could be due to older children spending more hours on smartphones [73].

Visual work on a digital screen demands continuous focusing and refocusing in an attempt to see the pixelated characters clearly.

Frequent eye movements to maintain focus lead to fatigue and eye strain. Shorter digital screen distance, a constant convergence, and accommodative demand further aggravate the asthenopic symptoms associated with DES [38, 74–76].

Prolonged duration (> 4 h), improper posture, and inadequate lighting conditions are directly proportional to the DES symptoms [38, 77]. Non-ocular symptoms associated with eye strain include stiff neck, general fatigue, headache, and backache [78, 79].

Digital screen-time has also been considered as a potential modifiable environmental risk factor that can increase the risk of myopia progression. Prevention of myopia progression has been prioritized due to the associated risks of myopic macular degeneration, retinal detachment, glaucoma, and cataract [80].

Recommendations to alleviate DES include the ergonomic use of digital devices [74, 81, 82].

1. Average daily screen time should be reduced to a reasonable limit (≤ 4 h daily).
2. Digital device practices: proper ambient lighting, digital device positioning, adjusting image parameters (resolution, text size, contrast, luminance), and taking frequent breaks (20/20/20 strategy).
3. It is recommended to sit upright at a desk or table with screens approximately 20 inches from the eyes [6]. The height of the screen should be positioned lower than the height of the eyes, such that the viewing distance is 15–20° below the eye level. Frequent blinking of eyes minimizes the chances of developing dry eyes. The refence materials should be placed above the level of keyboard and below the level of monitor.
4. Environments with an illumination of over 1000 lx are known to decline user performance [83]. A contrast setting around 60–70% is considered comfortable by most people. The brightness should be adjusted such that the light coming from monitors matches the light in the surrounding workspace. Anti-glare screens can also help in reducing the amount of light reflected from the screens [1]. A clearly legible font of at least size 12 preferably in a dark color over light background should be chosen.
5. Screen time tracking allows to control excessive screen usage. It encourages to spend less time on digital devices.
6. Refractive error correction and use of glasses with antireflective coating [1, 6].
7. Public education about the lasting effects of excessive screen time and encouraging healthier lifestyle practices.
8. Parents should be counseled to monitor their child's screen usage and incorporate family time.
9. Encourage children towards outdoor recreational activities.

There is strong evidence that increased screen time is associated with higher risks of an unhealthy diet, cognitive outcome, interpersonal relationships, and quality of life among children and young adults [84]. With the recent explosion of digital electronic device usage among children and young adults, there is an urgent need to educate the parents, caregivers, and youth about limiting digital screen time and implementing ergonomic practices of screen exposure.

ROLE OF OPHTHALMOLOGISTS AND VISUAL HEALTH SPECIALISTS

There is a need to increase awareness about digital eye strain since digital screen devices have become an inseparable part of the lifestyle. Recently, the impact of digital eye strain (DES) has been felt across the population with the lockdowns and curfews imposed by the pandemic [53, 62]. In the urban locales, there is some awareness about DES, but this is lacking in the rural and lower socio-economic groups, both of whom have seen an increasing screen exposure in recent years.

Eye-health strategies and awareness campaigns need to target the at-risk population. Awareness amongst digital device users can be channelized through doctors (physicians and ophthalmologists), health care workers (optometrists, vision technicians, and nursing staff), and non-medical professionals (wellness professionals, health and fitness experts, and information technology team leaders). A special emphasis should be made to raise awareness among teachers, since they are the ones who can offer early detection of DES symptoms at school, which is more important in the present times considering the increased dependency of education on digital devices.

Screen users need to be told to recognize symptoms of digital eye strain such as asthenopia, headache, neckache, red eyes, watery eyes, or burning sensation in the eyes. They need to be encouraged to make specific changes such as improving lighting, minimizing glare, taking regular breaks from the screen, changing focus to a distance object intermittently, following the 20-20-20 rule (taking a 20-s break every 20 min to look at an object 20 feet away) and using ergonomic chairs to reduce eye strain [85]. Frequent blinking needs to be emphasized too. Typically, we blink 14–16 times a minute, but this reduces to 4–6 times a minute when using screens [18]. Persistent symptoms despite these changes mark the need for an ophthalmic exam.

Parents and caregivers need to be sensitized to digital eye strain in children. There is a significant gap in the knowledge concerning DES and its potential harm, indicating a need to increase awareness in this group [50]. Parents and caregivers need to pick up on early signs that a child may be straining the eyes. Children often do not express ocular discomfort but may manifest certain mannerisms such as forced blinking or avoidance of screens or complain of transient episodic eye pain, rubbing, or epiphora, which may indicate eye strain [45]. Pediatricians and visual health specialists need to brief parents and teachers to recognize these signs and take remedial measures such as reducing screen time, using larger high-resolution displays, adjusting the lighting, and increasing outdoor activity. Over-the-counter lubricant drops can be considered in case of persistent symptoms, but an ophthalmology consult should be scheduled.

Innovation in screen technology has reduced the incidence of digital eye strain. These include high-resolution screens with inbuilt antireflective coating, matte-finished glass, edge-to-edge displays, and image smoothening graphic effects. Specific applications which remind screen users to take regular breaks also help inculcate screen-friendly habits. Innovations in the optical segment such as antireflective coating, blue-light blocking glasses, and polaroid lenses are other recommended measures to reduce eye strain.

RESEARCH AND KNOWLEDGE GAPS

As it is pretty clear on the date that DES is not going to go away, it is essential from a public health perspective to focus on practical protective and preventive approaches concentrating on improving the vision-related quality of life of individuals affected with DES [86].

Despite the significant strides made concerning the understanding of DES, there are considerable gaps in research and knowledge pertinent to:

1. The symptomology of DES
2. Effective treatment strategies
3. Optimizing and customizing treatment options for different age groups based on the visual demands and symptoms
4. Preventative approaches to ameliorate the onset and severity of DES

The current assessment protocols for DES include aspects of understanding the visual symptoms in detail using a structured inventory, understanding task-specific visual demands, ergonomic concerns and considerations, comprehensive eye examination, refractive correction, binocular vision assessment, ocular surface assessment for dry eyes, and management based on the outcomes of the assessment [86–88].

Yet, in the symptomatology of DES, there is a considerable gap in understanding the association between the onset of visual symptoms and pre-existing visual dysfunctions. It has been shown that extensive use of digital devices can induce or exacerbate visual fatigue [3, 82, 83]. It is not clear if individuals who have a pre-existing binocular vision dysfunction, dry eyes, and related anomalies are at an increased risk for DES. Also, there is a considerable gap concerning the context of the type of digital device and the dynamic visual demands imposed by the same. Studies that aim at categorizing the visual symptoms based on the pre-existing visual dysfunction, visual needs, and visual profile can aid in a better understanding of the DES and can also provide insights into preventative approaches to mitigate the visual symptoms [12].

Management options for DES are symptoms-based and include a holistic and comprehensive approach, from the management of refractive errors, binocular vision anomalies, and ocular surface dryness to providing workplace recommendations to improve visual comfort. The global lifestyle disruptions due to COVID-19 resulted in a rapid rise in DES prevalence across all age groups [86, 89]. The impact of DES on children was highlighted by various researchers that pointed out the need for visual protection measures to be followed during online learning. This included using appropriate screen settings, illumination and earning environment settings, posture requirements, adopting a healthy lifestyle, and regular eye examination [86].

Nonetheless, there are barely any studies exploring the optimal environmental conditions and efficacy of visual hygiene measures in ameliorating DES onset and prevalence [90, 91]. Most of these guidelines are primarily expertise and consensus-based and need to be backed up by evidence. There is a clear need for further exploration to understand the cause-and-effect relationship between blue light and DES; when it comes to the effect of blue light illuminance and its association with visual fatigue, dry eyes, and retina damage [92], there is a clear need for further exploration to understand the cause-and-effect relationship between blue light and DES.

Similarly, there is a considerable lacuna in understanding mechanisms based on which anti-fatigue lenses work to reduce visual fatigue. Novel spectacle lens designs are being explored in this context. Hence, further explorations in this field should focus on recommendations for digital screens optimized to improve visual comfort [93] novel spectacle lens technologies to reduce visual fatigue associated with long hours of screen viewing, and inbuilt filters to optimize visual comfort [94]. A paradigm shift is required in our understanding of looking at DES as a man/instrument-made entity to explore customized solutions accordingly [91]. Overall, future research should focus on enhancing our understanding of DES from an etiological perspective, leading to evidence-based management options.

CONCLUSIONS

Digital eye strain has been on the rise since the beginning of the COVID-19 pandemic. An augmented growth pattern has been experienced with prevalence ranging from 5 to 65% in pre-COVID-19 studies to 80–94% in the COVID-19 era. The sudden steep increase in screen and chair time has led way to other silent pandemics like digital eye strain, myopia, musculoskeletal problems, obesity, diabetes etc. Digital device usage of more than 4 h/day, underlying refractive errors, female gender, and prior dry eyes are the most significant risk factors predisposing to DES. There is an urgent need for eye care professionals and vision health specialists to be well informed about DES. Awareness related to effects of excess screen time, ergonomic practices, and preventive measures needs to be spread especially among teachers, youngsters, and professionals exposed to excessive or prolonged screen time. The role of anti-glare screens, anti-fatigue lenses, and blue-blocking filters is still controversial and needs to be further explored. Future studies should focus on understanding the risk factors among different groups and the association between accommodative or binocular vision anomalies and DES.

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REFERENCES

1. American Optometric Association. Computer vision syndrome. 2017. http://www.aoa.org/patients-and-public/caring-for-your-vision/protecting-your-vision/computer-vision-syndrome?ss0=y. Accessed 22 Feb 2022.
2. The Vision Council. Eyes overexposed: The digital device dilemma: digital eye strain report. 2016. http://www.thevisioncouncil.org/content/digital-eye-strain. Accessed 24 Feb 2022.
3. Sheppard AL, Wolffsohn JS. Digital eye strain: prevalence, measurement and amelioration. BMJ Open Ophthalmol. 2018;3: e000146.
4. Németh J, Tapasztó B, Aclimandos WA, et al. Update and guidance on management of myopia. European Society of Ophthalmology in cooperation with International Myopia Institute. Eur J Ophthalmol. 2021;31(3):853–83.
5. Usgaonkar U, Shet Parkar SR, Shetty A. Impact of the use of digital devices on eyes during the lockdown period of COVID-19 pandemic. Indian J Ophthalmol. 2021;69(7):1901–6.
6. https://www.aao.org/eye-health/tips-prevention/computer-usage. 2022. Accessed 10 June 2022.
7. Hashim JH, Adman MA, Hashim Z, Mohd Radi MF, Kwan SC. COVID-19 epidemic in Malaysia: epidemic progression, challenges, and response. Front Public Health. 2021;7(9): 560592.
8. De' R, Pandey N, Pal A. Impact of digital surge during Covid-19 pandemic: a viewpoint on research and practice. Int J Inf Manag. 2020;55: 102171.
9. Dain SJ, McCarthy AK, Chan-Ling T. Symptoms in VDU operators. Am J Optom Physiol Opt. 1988;65(3):162–7.
10. Loh K, Redd S. Understanding and preventing computer vision syndrome. Malays Fam Physician. 2008;3(3):128–30.
11. Auffret É, Gomart G, Bourcier T, Gaucher D, Speeg-Schatz C, Sauer A. Perturbations oculaires secondaires à l'utilisation de supports numériques. Symptômes, prévalence, physiopathologie et prise en charge. J Fr Ophtalmol. 2021;44(10):1605–10.
12. Jaiswal S, Asper L, Long J, Lee A, Harrison K, Golebiowski B. Ocular and visual discomfort associated with smartphones, tablets and computers: what we do and do not know. Clin Exp Optom. 2019;102(5): 463–77.

13. Sheedy JE, Hayes JN, Engle J. Is all asthenopia the same? Optom Vis Sci. 2003;80(11):732–9.

14. Portello JK, Rosenfield M, Bababekova Y, Estrada JM, Leon A. Computer-related visual symptoms in office workers. Ophthalmic Physiol Opt. 2012;32(5):375–82.

15. Shukla Y. Accommodative anomalies in children. Indian J Ophthalmol. 2020;68(8):1520–5.

16. Hakala PT, Saarni LA, Punamäki R-L, Wallenius MA, Nygård C-H, Rimpelä AH. Musculoskeletal symptoms and computer use among Finnish adolescents - pain intensity and inconvenience to everyday life: a cross-sectional study. BMC Musculoskelet Disord. 2012;13(1):41.

17. Mohan A, Sen P, Peeush P, Shah C, Jain E. Impact of online classes and home confinement on myopia progression in children during COVID-19 pandemic: digital eye strain among kids (DESK) study 4. Indian J Ophthalmol. 2022;70(1):241–5.

18. Blehm C, Vishnu S, Khattak A, Mitra S, Yee RW. Computer vision syndrome: a review. Surv Ophthalmol. 2005;50(3):253–62.

19. Torsheim T, Eriksson L, Schnohr CH, Hansen F, Bjarnason T, Välimaa R. Screen-based activities and physical complaints among adolescents from the Nordic countries. BMC Public Health. 2010;10:324.

20. Breen R, Pyper S, Rusk Y, Dockrell S. An investigation of children's posture and discomfort during computer use. Ergonomics. 2007;50:1582–92.

21. Campbell FW, Robson JG, Westheimer G. Fluctuations of accommodation under steady viewing conditions. J Physiol. 1959;145(3):579–94.

22. Lawrenson JG, Hull CC, Downie LE. The effect of blue-light blocking spectacle lenses on visual performance, macular health and the sleep-wake cycle: a systematic review of the literature. Ophthalmic Physiol Opt. 2017;37(6):644–54.

23. Vera J, Redondo B, Ortega-Sanchez A, et al. Blue-blocking filters do not alleviate signs and symptoms of digital eye strain. Clin Exp Optom. 2022;20:1–6.

24. Rosenfield M, Li RT, Kirsch NT. A double-blind test of blue-blocking filters on symptoms of digital eye strain. Work. 2020;65(2):343–8.

25. Redondo B, Vera J, Ortega-Sánchez A, Molina R, Jiménez R. Effects of a blue-blocking screen filter on accommodative accuracy and visual discomfort. Ophthalmic Physiol Opt. 2020;40(6):790–800.

26. Palavets T, Rosenfield M. Blue-blocking filters and digital eyestrain. Optom Vis Sci. 2019;96(1):48–54.

27. Himebaugh NL, Begley CG, Bradley A, Wilkinson JA. Blinking and tear break-up during four visual tasks. Optom Vis Sci. 2009;86(2):E106–14.

28. Patel S, Henderson R, Bradley L, Galloway B, Hunter L. Effect of visual display unit use on blink rate and tear stability. Optom Vis Sci. 1991;68(11):888–92.

29. Tsubota K, Nakamori K. Dry eyes and video display terminals. N Engl J Med. 1993;328(8):584.

30. Sheedy JE, Gowrisankaran S, Hayes JR. Blink rate decreases with eyelid squint. Optom Vis Sci. 2005;82(10):905–11.

31. Hirota M, Uozato H, Kawamorita T, Shibata Y, Yamamoto S. Effect of incomplete blinking on tear film stability. Optom Vis Sci. 2013;90(7):650–7.

32. Courtin R, Pereira B, Naughton G, et al. Prevalence of dry eye disease in visual display terminal workers: a systematic review and meta-analysis. BMJ Open. 2016;6(1): e009675.

33. The epidemiology of dry eye disease: report of the Epidemiology Subcommittee of the International Dry Eye WorkShop. Ocul Surf. 2007;5(2):93–107.

34. Vilela MA, Pellanda LC, Fassa AG, Castagno VD. Prevalence of asthenopia in children: a systematic review with meta-analysis. J Pediatr (Rio J). 2015;91(4):320–5.

35. Ichhpujani P, Singh RB, Foulsham W, Thakur S, Lamba AS. Visual implications of digital device usage in school children: a cross-sectional study. BMC Ophthalmol. 2019;19(1):76.

36. Moon JH, Lee MY, Moon NJ. Association between video display terminal use and dry eye disease in school children. J Pediatr Ophthalmol Strabismus. 2014;51(2):87–92.

37. Kaur S, Sukhija J, Khanna R, Takkar A, Singh M. Diplopia after excessive smart phone usage. Neuroophthalmology. 2018;43(5):323–6.

38. Cantó-Sancho N, Ronda E, Cabrero-García J, et al. Rasch-Validated Italian Scale for diagnosing digital eye strain: the computer vision syndrome questionnaire IT©. Int J Environ Res Public Health. 2022;19(8):4506.

39. Auffret E, Mielcarek M, Bourcier T, Delhommais A, Speeg-Schatz C, Sauer A. Stress oculaire induit par les écrans. Analyses des symptômes fonctionnels et de l'équilibre binoculaire chez des utilisateurs intensifs. J Fr Ophtalmol. 2022;45(4):438–45.

40. Moore PA, Wolffsohn JS, Sheppard AL. Attitudes of optometrists in the UK and Ireland to Digital Eye Strain and approaches to assessment and

management. Ophthalmic Physiol Opt. 2021;41(6): 1165–75.

41. Zayed HAM, Saied SM, Younis EA, Atlam SA. Digital eye strain: prevalence and associated factors among information technology professionals. Egypt Environ Sci Pollut Res Int. 2021;28(20):25187–95.

42. Meyer D, Rickert M, Kollbaum P. Ocular symptoms associated with digital device use in contact lens and non-contact lens groups. Cont Lens Anterior Eye. 2021;44(1):42–50.

43. Al Dandan O, Hassan A, Al Shammari M, Al Jawad M, Alsaif HS, Alarfaj K. Digital eye strain among radiologists: a survey-based cross-sectional study. Acad Radiol. 2021;28(8):1142–8.

44. Mohan A, Sen P, Shah C, Jain E, Jain S. Prevalence and risk factor assessment of digital eye strain among children using online e-learning during the COVID-19 pandemic: digital eye strain among kids (DESK study-1). Indian J Ophthalmol. 2021;69(1): 140–4.

45. Demirayak B, Yılmaz Tugan B, Toprak M, Çinik R. Digital eye strain and its associated factors in children during the COVID-19 pandemic. Indian J Ophthalmol. 2022;70(3):988–92.

46. Kaur K, Kannusamy V, Gurnani B, Mouttapa F, Balakrishnan L. Knowledge, attitude, and practice patterns related to digital eye strain among parents of children attending online classes in the COVID-19 era: a cross-sectional study. J Pediatr Ophthalmol Strabismus. 2021;20:1–12.

47. Mohan A, Sen P, Mujumdar D, Shah C, Jain E. Series of cases of acute acquired comitant esotropia in children associated with excessive online classes on smartphone during COVID-19 pandemic; digital eye strain among kids (DESK) study-3. Strabismus. 2021;29(3):163–7.

48. Mohan A, Sen P, Shah C, Datt K, Jain E. Binocular accommodation and vergence dysfunction in children attending online classes during the COVID-19 pandemic: Digital Eye Strain in Kids (DESK) Study-2. J Pediatr Ophthalmol Strabismus. 2021;58(4): 224–31.

49. Alabdulkader B. Effect of digital device use during COVID-19 on digital eye strain. Clin Exp Optom. 2021;104(6):698–704.

50. Kumari K, Kaur S, Sukhija J. Commentary: myopia progression during the COVID-19 pandemic. Indian J Ophthalmol. 2022;70(1):245–6.

51. Wang J, Li Y, Musch DC, et al. Progression of myopia in school-aged children after COVID-19 home confinement. JAMA Ophthalmol. 2021;139(3):293–300.

52. Wang W, Zhu L, Zheng S, et al. Survey on the progression of myopia in children and adolescents in Chongqing during COVID-19 pandemic. Front Public Health. 2021;28(9): 646770.

53. Wangsan K, Upaphong P, Assavanopakun P, et al. Self-reported computer vision syndrome among Thai University students in virtual classrooms during the COVID-19 pandemic: prevalence and associated factors. Int J Environ Res Public Health. 2022;19(7):3996.

54. Cai T, Zhao L, Kong L, Du X. Complex interplay between COVID-19 lockdown and myopic progression. Front Med (Lausanne). 2022;21(9): 853293.

55. Basnet A, Pathak SB, Marasini A, Pandit R, Pradhan A. Digital eye strain among adults presenting to tertiary care hospital in the era of COVID-19 pandemic: a descriptive cross-sectional study. JNMA J Nepal Med Assoc. 2022;60(245):22–5.

56. Regmi A, Suresh J, Asokan R. Changes in work patterns during COVID-19 lockdown and its impact on the eyes and body. Clin Exp Optom. 2022;14: 1–7.

57. Gupta R, Chauhan L, Varshney A. Impact of E-schooling on digital eye strain in coronavirus disease era: a survey of 654 students. J Curr Ophthalmol. 2021;33(2):158–64.

58. Salinas-Toro D, Cartes C, Segovia C, et al. High frequency of digital eye strain and dry eye disease in teleworkers during the coronavirus disease (2019) pandemic. Int J Occup Saf Ergon. 2021;7:1–6.

59. Zheng Y, Wang W, Zhong Y, et al. A peer-to-peer live-streaming intervention for children during COVID-19 homeschooling to promote physical activity and reduce anxiety and eye strain: cluster randomized controlled trial. J Med Internet Res. 2021;23(4): e24316.

60. Gammoh Y. Digital eye strain and its risk factors among a university student population in Jordan: a cross-sectional study. Cureus. 2021;13(2): e13575.

61. Ganne P, Najeeb S, Chaitanya G, Sharma A, Krishnappa NC. Digital eye strain epidemic amid COVID-19 pandemic: a cross-sectional survey. Ophthalmic Epidemiol. 2021;28(4):285–92.

62. Bahkir FA, Grandee SS. Impact of the COVID-19 lockdown on digital device-related ocular health. Indian J Ophthalmol. 2020;68(11):2378–83.

63. MedlinePlus [Internet]. Bethesda (MD): National Library of Medicine (US). Updated Jun 24. https://medlineplus.gov/. Accessed 01 Jun 2020.

64. Pellegrini M, Bernabei F, Scorcia V, Giannaccare G. May home confinement during the COVID-19 outbreak worsen the global burden of myopia? Graefes Arch Clin Exp Ophthalmol. 2020;258(9): 2069–70.

65. Wang G, Zhang Y, Zhao J, Zhang J, Jiang F. Mitigate the effects of home confinement on children during the COVID-19 outbreak. Lancet. 2020;395(10228):945–7.

66. Wong CW, Tsai A, Jonas JB, et al. Digital screen time during the COVID-19 pandemic: risk for a further myopia boom? Am J Ophthalmol. 2021;223:333–7.

67. Munshi S, Varghese A, Dhar-Munshi S. Computer vision syndrome-A common cause of unexplained visual symptoms in the modern era. Int J Clin Pract. 2017;71(7): e12962.

68. Cole BL, Maddocks JD, Sharpe K. Effect of VDUs on the eyes: report of a 6-year epidemiological study. Optom Vis Sci. 1996;73(8):512–28.

69. Hayes JR, Sheedy JE, Stelmack JA, Heaney CA. Computer use, symptoms, and quality of life. Optom Vis Sci. 2007;84(8):738–44.

70. Hagan S, Lory B. Prevalence of dry eye among computer users. Optom Vis Sci. 1998;75(10):712–3.

71. Reddy SC, Low CK, Lim YP, Low LL, Mardina F, Nursaleha MP. Computer vision syndrome: a study of knowledge and practices in university students. Nepal J Ophthalmol. 2013;5(2):161–8.

72. Al-Mohtaseb Z, Schachter S, Shen Lee B, Garlich J, Trattler W. The relationship between dry eye disease and digital screen use. Clin Ophthalmol. 2021;10(15):3811–20.

73. Moon JH, Kim KW, Moon NJ. Smartphone use is a risk factor for pediatric dry eye disease according to region and age: a case control study. BMC Ophthalmol. 2016;16(1):188.

74. Jaschinski W, Heuer H, Kylian H. Preferred position of visual displays relative to the eyes: a field study of visual strain and individual differences. Ergonomics. 1998;41(7):1034–49.

75. Shantakumari N, Eldeeb R, Sreedharan J, Gopal K. Computer use and vision-related problems among university students in Ajman, United Arab Emirates. Ann Med Health Sci Res. 2014;4(2):258–63.

76. Jaschinski-Kruza W. Eyestrain in VDU users: viewing distance and the resting position of ocular muscles. Hum Factors. 1991;33(1):69–83.

77. Owens DA. The resting state of the eyes. Am Sci. 1984;72(4):378–87.

78. Kim J, Hwang Y, Kang S, et al. Association between exposure to smartphones and ocular health in adolescents. Ophthalmic Epidemiol. 2016;23(4): 269–76.

79. Hall L, Coles-Brennan C. Digital eye strain: more screen time = more digital eye strain. Contact Lens Spectrum. 2015;30:38–40.

80. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. Ophthalmology. 2016;123(5):1036–42.

81. Borhany T, Shahid E, Siddique WA, Ali H. Musculoskeletal problems in frequent computer and internet users. J Family Med Prim Care. 2018;7(2): 337–9.

82. Leung TW, Li RW, Kee CS. Blue-light filtering spectacle lenses: optical and clinical performances. PLoS ONE. 2017;12(1): e0169114.

83. Liu P, Zafar F, Badano A. The effect of ambient illumination on handheld display image quality. J Digit Imaging. 2014;27(1):12–8.

84. LeBlanc AG, Spence JC, Carson V, et al. Systematic review of sedentary behaviour and health indicators in the early years (aged 0–4 years). Appl Physiol Nutr Metab. 2012;37(4):753–72.

85. Hussaindeen JR, Gopalakrishnan A, Sivaraman V, Swaminathan M. Managing the myopia epidemic and digital eye strain post COVID-19 pandemic: what eye care practitioners need to know and implement? Indian J Ophthalmol. 2020;68(8): 1710–2.

86. Fan Q, Wang H, Kong W, Zhang W, Li Z, Wang Y. online learning-related visual function impairment during and after the COVID-19 pandemic. Front Public Health. 2021;29(9): 645971.

87. Rosenfield M. Computer vision syndrome: a review of ocular causes and potential treatments. Ophthalmic Physiol Opt. 2011;31(5):502–15.

88. Coles-Brennan C, Sulley A, Young G. Management of digital eye strain. Clin Exp Optom. 2019;102(1): 18–29.

89. Liu J, Li B, Sun Y, Chen Q, Dang J. Adolescent vision health during the outbreak of COVID-19:

association between digital screen use and myopia progression. Front Pediatr. 2021;25(9): 662984.

90. Boadi-Kusi SB, Adueming PO, Hammond FA, Antiri EO. Computer vision syndrome and its associated ergonomic factors among bank workers. Int J Occup Saf Ergon. 2022;28(2):1219–26.

91. Sánchez-Brau M, Domenech-Amigot B, Brocal-Fernández F, Seguí-Crespo M. Computer vision syndrome in presbyopic digital device workers and progressive lens design. Ophthalmic Physiol Opt. 2021;41(4):922–31.

92. Ouyang X, Yang J, Hong Z, Wu Y, Xie Y, Wang G. Mechanisms of blue light-induced eye hazard and protective measures: a review. Biomed Pharmacother. 2020;130: 110577.

93. Yuan K, Zhu H, Mou Y, et al. Effects on the ocular surface from reading on different smartphone screens: a prospective randomized controlled study. Clin Transl Sci. 2021;14(3):829–36.

94. https://visionscienceacademy.org/digital-eye-strain-there-is-more-to-come-more-to-explore-part-1/. 2022. Accessed 02 Mar 2022