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Remote learning and increased screen time during the COVID-19 pandemic as risk factors for Digital Eye Strain: a review

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Abstract:

Digital Eye Strain (DES), also referred to as Computer Vision Syndrome (CVS), is a functional, symptom-based condition associated with prolonged digital display use and characterised by visual fatigue, ocular discomfort or dryness, blurred or fluctuating vision, and headache. During the COVID-19 pandemic, lockdown measures and school closures accelerated the shift towards remote learning, substantially increasing daily screen exposure among children, adolescents, and university students. This narrative review evaluates evidence on the relationship between remote learning, increased screen time during the COVID-19 pandemic, and the risk of Digital Eye Strain. Across pandemic-era studies, prolonged screen-based education was generally associated with a higher prevalence of DES-related symptoms in student populations. However, the available evidence is predominantly observational and relies largely on self-reported screen exposure and subjective symptom measures, with substantial heterogeneity in outcome definitions and assessment tools.

Overall, the COVID-19 pandemic appears to have amplified pre-existing screen-related risk factors for Digital Eye Strain rather than introduced a novel ocular condition, while expanding the size of the exposed population. Although causal inference is limited, the consistency of findings across age groups supports the clinical relevance of Digital Eye Strain in remote learning contexts. Future research should prioritise longitudinal designs, clearer differentiation

between educational and recreational screen use, and the integration of objective measures of visual behaviour and ocular surface function.

Keywords: digital eye strain; computer vision syndrome; remote learning; screen time; COVID-19; visual ergonomics.

1. Introduction

Digital Eye Strain (DES), also referred to as Computer Vision Syndrome (CVS), describes a cluster of ocular and visual symptoms associated with prolonged use of digital display devices. Commonly reported complaints include visual fatigue (asthenopia), ocular discomfort or dryness, blurred or fluctuating vision, headache, and difficulty sustaining near focus [1-3]. Rather than representing a single, well-defined ocular disease entity, DES is best understood as a functional, symptom-based construct whose expression depends on visual behaviour, task demands, and environmental conditions [3-4]. This conceptual framework contributes to substantial variability in reported prevalence and symptom profiles across studies [5].

The mechanisms underlying Digital Eye Strain are multifactorial. Symptoms may arise from ocular surface stress related to reduced or incomplete blinking and tear film instability, increased accommodative and binocular vision demands during sustained near fixation, and suboptimal viewing conditions such as inappropriate viewing distance, glare, or poor visual ergonomics [2,6-7]. These pathways have been well described in pre-pandemic literature on prolonged screen-based tasks and provide a biologically plausible framework for interpreting screen-related visual symptoms.

With the widespread integration of screens into daily life, DES has been reported as common among digital display users [4,8-9]. However, differences in outcome definitions, symptom thresholds, and measurement instruments substantially limit comparability between studies [3,8]. Although validated questionnaires such as the Computer Vision Syndrome Questionnaire (CVS-Q) demonstrate the feasibility of standardised symptom assessment, they also highlight ongoing challenges related to symptom specificity and heterogeneity across populations and study designs [5].

During the COVID-19 pandemic, patterns of digital device use changed abruptly. Lockdown measures, school closures, and home confinement led to a rapid and widespread shift towards remote learning, resulting in substantial increases in daily screen exposure among children, adolescents, and university students [10-13]. Importantly, remote learning represents not only

an increase in total screen time but also a distinct exposure context characterised by prolonged near fixation, limited variability in viewing distance, and reduced opportunities for spontaneous visual breaks [12-13]. These characteristics correspond closely to mechanisms implicated in the development of Digital Eye Strain.

Across pandemic-era studies, increased screen exposure during periods of remote learning was consistently associated with a higher prevalence of DES-like complaints, including ocular discomfort, dry eye-related symptoms, and visual fatigue, across both paediatric and adult student populations [11,14-15]. However, most available evidence remains observational and relies predominantly on self-reported screen time estimates and subjective symptom questionnaires [10,12-13,16]. Taken together, the available literature supports the interpretation that the COVID-19 pandemic predominantly intensified previously described exposure patterns and risk pathways associated with Digital Eye Strain, rather than introducing a novel clinical entity, while simultaneously expanding the size of the exposed population due to the scale and structure of remote learning demands, particularly among children and adolescents exposed to prolonged online education during lockdown periods [2-3,17].

The aim of this narrative review is to critically evaluate current evidence on the relationship between remote learning, increased screen exposure during the COVID-19 pandemic, and the risk of Digital Eye Strain. Peer-reviewed literature was identified through systematic searches of PubMed, supplemented by searches of Web of Science to capture relevant ophthalmological, optometric, and public health studies not indexed in PubMed, as well as targeted screening of reference lists via Google Scholar (last search: December 2025). Studies published between 2020 and 2025 were prioritised to reflect pandemic and post-pandemic evidence, complemented by earlier seminal mechanistic and clinical works relevant to Digital Eye Strain pathophysiology. Eligible articles included observational and interventional studies, as well as systematic and narrative reviews reporting DES-related outcomes or closely related ocular surface and visual symptoms associated with digital device use. Given the narrative design of the review and the substantial heterogeneity in study designs, populations, and outcome measures, no formal risk of bias assessment was undertaken; however, methodological limitations are explicitly addressed in the Discussion.

2. Digital Eye Strain: underlying mechanisms

Digital Eye Strain (DES) is a multifactorial, symptom-based condition arising from the interaction of ocular surface factors, visual demands related to accommodation and vergence, and environmental or behavioural influences, which together determine individual symptom

profiles and severity [1-2,18]. Rather than reflecting a single pathological process, DES represents a functional response of the visual system to sustained digital display use under specific task and environmental conditions [3].

Compared with traditional near work, digital device use is characterised by prolonged fixation at relatively fixed viewing distances, high visual and cognitive demand, and reduced variability in accommodative and vergence activity. These features increase overall visual load and are thought to contribute to the development of DES symptoms, particularly during prolonged and uninterrupted screen-based tasks such as those frequently encountered during remote learning [2,19].

2.1 Ocular surface alterations and blink behaviour

Altered blink behaviour is one of the most consistently reported mechanisms underlying Digital Eye Strain. Experimental and observational studies have demonstrated a marked reduction in spontaneous blink rate during prolonged screen-based tasks, particularly during computer-based visual activities requiring sustained attention [7,20-22]. This phenomenon appears to be primarily driven by sustained visual attention and cognitive engagement rather than by the physical properties of the display itself [22].

Reduced blink frequency and incomplete blinking impair normal tear film renewal, leading to tear film instability, increased evaporation, and ocular surface stress [7,20,23]. As a consequence, individuals may experience symptoms of ocular dryness, burning sensation, foreign body sensation, and surface-related discomfort during or after prolonged screen use [2,8].

Although Digital Eye Strain is not synonymous with dry eye disease, repeated episodes of tear film instability during sustained screen-based tasks may exacerbate pre-existing ocular surface vulnerability or contribute to dry eye-related symptoms, even in younger and otherwise healthy populations [4,24]. This mechanism is particularly relevant in the context of remote learning, where prolonged visual attention during online lectures and examinations may further suppress blink activity and increase cumulative ocular surface stress [12-13].

2.2 Accommodative and vergence stress

Prolonged digital device use imposes substantial demands on the accommodative and vergence systems during sustained near fixation. Extended near work has been associated with accommodative fatigue, reduced accommodative facility, transient accommodative insufficiency, and vergence stress, manifesting clinically as blurred or fluctuating vision, delayed refocusing, asthenopia, and frontal headache [1,6,18].

Compared with printed text, digital displays often require sustained focus on characters with less sharply defined edges and variable luminance, which may increase accommodative effort and overall visual load [2,19]. In addition, frequent shifts between near and intermediate viewing distances, common during multitasking across digital devices and platforms, may further exacerbate vergence stress and binocular discomfort [6].

During periods of remote learning, accommodative and vergence demands may be intensified by prolonged, task-driven near fixation with limited opportunities for distance viewing or spontaneous visual breaks, increasing susceptibility to visual fatigue and asthenopic symptoms [12-13].

2.3 Visual ergonomics and environmental factors

Visual ergonomics play a critical role in the development and exacerbation of Digital Eye Strain. Suboptimal screen height and gaze angle, inappropriate viewing distance, glare or reflections, and inadequate ambient lighting can increase visual effort and contribute to ocular discomfort during prolonged screen use [2,25]. Poor posture and prolonged static positioning may further amplify symptom burden through musculoskeletal strain and behavioural changes that indirectly reduce blink efficiency during visually demanding tasks [25-26].

During the COVID-19 pandemic, remote learning frequently occurred in home-based environments characterised by substantial variability in workstation design, screen size, viewing distance, and lighting conditions, many of which were not optimised for sustained near work [12,27]. Such non-standardised viewing conditions correspond to established ergonomic risk factors for Digital Eye Strain and may have contributed to increased symptom reporting during prolonged periods of home-based education, particularly among users relying on portable digital devices with shorter viewing distances [12,27-28].

2.4 Refractive errors and individual susceptibility

Uncorrected or undercorrected refractive errors may exacerbate Digital Eye Strain symptoms by increasing accommodative demand during sustained near tasks. Even minor refractive inaccuracies can contribute to visual fatigue and asthenopia during prolonged digital device use [1-2,8]. Individuals with pre-existing binocular vision anomalies or reduced accommodative reserve, including presbyopic users, appear particularly susceptible to DES-related symptoms [6,18].

Susceptibility to Digital Eye Strain varies widely and is influenced by age, ocular surface status, duration and continuity of daily screen exposure, device type, and behavioural factors such as

visual hygiene practices and break patterns [29-30]. This inter-individual variability contributes substantially to heterogeneity in reported prevalence and symptom severity across studies and complicates comparisons between populations and exposure contexts [5,29].

2.5 Digital Eye Strain as a functional condition

Digital Eye Strain is best conceptualised as a functional, exposure-dependent condition rather than a structural ocular disease [2,4]. Symptoms are closely linked to visual behaviour, task demands, and environmental context and often fluctuate with changes in screen exposure, viewing conditions, and the implementation of behavioural or ergonomic interventions [2]. Nevertheless, persistent or recurrent symptoms may negatively affect academic performance, work productivity, and quality of life, underscoring that a functional and exposure-dependent condition is not necessarily benign in its long-term impact [26,30].

This conceptualisation is consistent with contemporary ocular surface frameworks that emphasise dynamic interactions between environmental exposures, visual behaviour, and tear film homeostasis, and that recommend standardised diagnostic approaches for characterising ocular surface status in both research and clinical practice [23,31-32].

3. Screen time and remote learning during the COVID-19 pandemic

3.1 Changes in educational screen exposure during the pandemic

The COVID-19 pandemic resulted in a rapid and large-scale global shift towards remote learning, fundamentally altering patterns of digital device use across all levels of education [10-11,16]. School closures and home confinement measures led to the widespread adoption of online educational platforms, often implemented without standardised guidance on screen time management, visual ergonomics, or ocular health considerations [27]. As a consequence, multiple studies and meta-analyses documented substantial increases in daily screen exposure among children, adolescents, and university students engaged in formal education during lockdown periods [11,33-34].

In many settings, educational screen use prior to the COVID-19 pandemic was more limited and frequently supplementary, involving shorter and less continuous periods of digital engagement [11]. During pandemic-related lockdowns, however, remote learning became the primary mode of instruction, often requiring several consecutive hours of screen-based activities each day [33]. This shift substantially increased both the duration and continuity of sustained near visual tasks performed on digital displays, contributing to unprecedented cumulative screen exposure in student populations [11,35].

3.2 Characteristics of remote learning as a visual task

Unlike recreational screen use, which is often more intermittent and self-regulated, remote learning imposed structured and sustained visual demands that are largely non-discretionary [33,36]. Educational activities such as online lectures, virtual discussions, digital assignments, and remote examinations typically require prolonged, near visual tasks, frequently performed continuously for several hours [33,37].

In many cases, these activities were conducted with limited opportunities for spontaneous visual breaks and reduced variability in viewing distance, particularly during long virtual lectures or examination sessions [33]. Such exposure characteristics distinguish remote learning from typical pre-pandemic educational screen use and correspond closely to established mechanisms implicated in the development of Digital Eye Strain [3].

3.3 Ergonomic and behavioural context of home-based learning

Remote learning environments introduced additional visual challenges related not only to increased screen exposure but also to suboptimal workspace conditions [27]. Several studies reported that students frequently attend online classes using laptops, tablets, or smartphones in non-ergonomic settings such as beds, couches, or kitchen tables, resulting in substantial variability in viewing distance, posture, screen height, and lighting conditions [27]. These improvised workstations are associated with non-optimal visual ergonomics, which are known to increase visual effort and ocular discomfort during prolonged screen use [25-26].

Another important feature of pandemic-related screen use was the reduction in natural visual breaks during daily activities [33]. Traditional classroom settings typically involved physical movement, changes in viewing distance, and intermittent rest periods, whereas remote learning frequently required prolonged uninterrupted near fixation [33]. In parallel, lockdown measures substantially reduced outdoor activities and opportunities for distance viewing, factors recognised as protective against visual fatigue and ocular discomfort [11].

Although assessment of screen exposure during the pandemic has relied largely on self-reported questionnaires and survey-based studies, which are subject to recall bias and heterogeneity in screen time definitions [10,14], the overall pattern across studies remains consistent. Remote learning during the COVID-19 pandemic was associated with a marked increase in cumulative screen exposure under behavioural and ergonomic conditions conducive to visual strain [10,33].

This context provides a necessary framework for interpreting subsequent evidence linking increased screen time with Digital Eye Strain symptoms.

4. Evidence linking remote learning and increased screen time with Digital Eye Strain

4.1 Overall association between screen exposure and DES during remote learning

A growing body of observational evidence indicates a consistent association between increased screen exposure during periods of remote learning and a higher prevalence of Digital Eye Strain (DES) symptoms. Most available data derive from cross-sectional surveys conducted during the COVID-19 pandemic and primarily involve children, adolescents, and young adults exposed to prolonged daily use of digital devices for educational purposes [10,14,16,33].

Across multiple studies, longer daily screen exposure is associated with both higher frequency and greater severity of DES-related symptoms, including eye fatigue, ocular dryness or burning, blurred vision, and headache. In several reports, students engaged in screen-based learning for more than four to six hours per day report a substantially greater symptom burden compared with those experiencing shorter daily exposure durations [10,14,28,33]. In some studies, symptom prevalence appears to increase with cumulative daily screen exposure, suggesting a potential exposure–response relationship; however, formal dose–response modelling is rarely performed and findings are based on self-reported screen time estimates, which should therefore be interpreted cautiously [10,16].

Evidence from both paediatric and adult populations further suggests that DES symptom burden during periods of remote learning is influenced not only by total screen duration but also by concurrent factors such as limited visual breaks, suboptimal ergonomic conditions, and pre-existing ocular surface complaints [3,26,27]. Taken together, these findings support a consistent observational association between prolonged screen exposure during remote learning and increased reporting of Digital Eye Strain symptoms during the COVID-19 pandemic.

4.2 Children and adolescents

Studies involving school-aged children and adolescents demonstrate patterns broadly comparable to those observed in older populations. Increased screen exposure related to online classes is consistently associated with a higher prevalence of ocular discomfort and visual fatigue, particularly among younger children who may have limited awareness of visual hygiene practices and fewer opportunities for self-regulated visual breaks [15,33].

In this age group, DES-related symptoms frequently co-occur with behavioural changes such as reduced outdoor activity, altered sleep patterns, and prolonged uninterrupted near work.

These factors may indirectly contribute to ocular surface disturbances and visual fatigue during sustained screen use and represent important potential confounders in observational studies conducted during lockdown periods [11,15,17]. From a broader ocular surface perspective, this vulnerability is consistent with epidemiological frameworks describing dry eye–related risk factors and environmental stressors in younger populations, although Digital Eye Strain and dry eye disease remain distinct clinical entities [38].

4.3 University students and young adults

University students and young adults represent one of the most extensively studied populations during the COVID-19 pandemic. Survey-based studies conducted during periods of mandatory remote learning report that a substantial proportion of students experience new-onset or worsening ocular and visual symptoms compared with the pre-pandemic period [14,28,36].

Reported risk factors include prolonged uninterrupted screen use, frequent reliance on smartphones for educational purposes, suboptimal lighting conditions, and lack of regular visual breaks, all of which are associated with increased DES symptom burden in this population [14,28]. In addition to total screen duration, the type of digital device used during remote learning appears to influence symptom severity. Use of smaller screens, such as smartphones and tablets, is associated with shorter viewing distances, increased accommodative demand, and greater visual effort, potentially exacerbating visual fatigue and ocular discomfort during sustained near work [19,28].

Emerging evidence further suggests that prolonged digital screen exposure in university students is associated with dry eye–related symptoms, even in otherwise healthy young adults. Studies conducted during and after the pandemic report associations between intensive digital device use and increased ocular surface complaints, highlighting partial overlap between Digital Eye Strain and dry eye related symptomatology while maintaining their distinction as clinical constructs [24,39].

Conversely, use of larger desktop monitors with adjustable viewing positions and more stable viewing distances is, in some studies, associated with lower symptom intensity compared with handheld devices. However, available evidence remains inconsistent and context-dependent, and device-related effects cannot be readily separated from behavioural and ergonomic factors influencing visual load [19,26].

4.4 Modifying and risk factors

From a mechanistic perspective, many ocular surface symptoms reported during periods of intensive remote learning are consistent with pathways described in the TFOS DEWS II framework, including tear film instability, increased evaporative stress, and tear hyperosmolarity [23,38,40]. Importantly, the association between digital display use, reduced blink rate, and tear film disruption is not a novel observation. Early investigations of video display terminal use demonstrate significant blink suppression and tear film instability during sustained screen-based tasks well before the COVID-19 pandemic [7,20].

Beyond shared mechanistic pathways, several factors modify the relationship between screen exposure and Digital Eye Strain symptom expression. These include uncorrected or undercorrected refractive errors, pre-existing ocular surface vulnerability, binocular vision anomalies, and inadequate workstation ergonomics, all of which increase visual demand and reduce tolerance to prolonged near work [1-3,26-27].

Recent evidence further suggests that prolonged digital screen exposure may be associated with dry eye-related symptoms even in young adult populations, raising the possibility that some ocular surface complaints observed during pandemic-related remote learning persist beyond emergency conditions [24,30,39,41]. However, this overlap does not imply equivalence between Digital Eye Strain and dry eye disease but rather reflects shared exposure-related stressors acting on different components of the visual and ocular surface system.

Demographic characteristics such as female sex and older age within student populations are also reported as potential risk modifiers. Findings across studies remain inconsistent and likely reflect behavioural patterns, baseline ocular surface differences, or exposure characteristics rather than independent biological susceptibility [14,29].

4.5 Quality and limitations of the available evidence

Despite relatively consistent observational associations between increased screen exposure and DES-related symptoms, the overall quality of the available evidence remains moderate. Most pandemic-era studies relied primarily on self-reported screen time estimates and subjective symptom questionnaires, often without the use of standardised or universally accepted diagnostic criteria for Digital Eye Strain [3,5,13]. Substantial heterogeneity in outcome definitions, symptom thresholds, and assessment instruments further limits direct comparability across studies and contributes to wide variation in reported prevalence estimates.

Objective assessments of visual function, including blink behaviour, tear film stability, accommodative performance, or binocular coordination, were rarely incorporated. In addition, the predominance of cross-sectional study designs limits inference regarding temporal relationships or causality between screen exposure and symptom development [3,29]. Relatively few investigations clearly differentiated between educational and recreational screen use, making it difficult to isolate the specific contribution of remote learning to observed increases in DES symptoms [11,13-14].

Nevertheless, when considered collectively, the available evidence supports the conclusion that remote learning during the COVID-19 pandemic was associated with substantial increases in screen exposure and higher reporting of Digital Eye Strain symptoms across multiple age groups. Although causality cannot be definitively established, the consistency of findings across populations, study settings, and geographical regions, including evidence synthesised in recent systematic reviews and meta-analyses, suggests a clinically relevant relationship that warrants further investigation using longitudinal designs and objective visual assessments [16,29-30].

5. Discussion

5.1 Principal findings

The findings summarised in this review indicate a consistent observational association between increased digital screen exposure and a higher prevalence of Digital Eye Strain (DES) symptoms in student populations. Across pandemic-era studies, higher rates of ocular discomfort, visual fatigue, and dry eye-related symptoms were reported in children, adolescents, and young adults exposed to prolonged daily screen use during periods of remote learning, supporting the clinical relevance of sustained, task-driven near work as a key exposure context [10,12-13,16,33].

Importantly, these findings do not suggest the emergence of a novel ocular condition during the COVID-19 pandemic. Rather, they are consistent with pre-existing models of Digital Eye Strain, in which symptom expression reflects the interaction between visual behaviour, task demands, and environmental conditions [2-3]. The pandemic context primarily intensified established risk pathways by increasing the duration, continuity, and non-discretionary nature of screen-based near work, while simultaneously reducing opportunities for visual variability and spontaneous rest.

Although the observed associations are biologically plausible and clinically relevant, the overall strength of the available evidence remains limited by important methodological constraints. Digital Eye Strain remains a symptom-based construct characterised by heterogeneous

definitions, and most pandemic-era studies relied predominantly on self-reported screen exposure and subjective symptom questionnaires rather than objective assessments of ocular surface or visual function [3,5,29]. As a result, while increased total screen exposure represents a fundamental risk factor for DES, remote learning should be interpreted as a specific exposure context that amplifies this risk through prolonged, non-discretionary near work with limited visual variability and reduced opportunities for spontaneous visual breaks, rather than as an independent or singular causal factor [12-13].

5.2 Methodological limitations of the pandemic-era evidence

A major limitation of the pandemic-era literature is the predominance of cross-sectional study designs, which preclude inference of causality or clear temporal relationships between screen exposure and symptom development [13,29]. In addition, most studies relied on self-reported screen time estimates and subjective symptom questionnaires, which are inherently prone to recall bias and substantial variability in how both “screen time” and Digital Eye Strain symptoms are defined [3,13].

This methodological heterogeneity has long been recognised in Digital Eye Strain research and contributes to wide variation in reported prevalence and symptom profiles across studies [3,29]. Although validated instruments such as the Computer Vision Syndrome Questionnaire (CVS-Q) are available, they were not consistently adopted in pandemic-era research, limiting cross-study comparability and inflating heterogeneity [3,5]. Moreover, relatively few studies incorporated objective measures of visual behaviour or ocular surface function, further constraining the interpretability of self-reported symptom outcomes.

All these limitations complicate synthesis across studies and underscore the need for greater standardisation of outcome measures, clearer operational definitions of screen exposure, and the integration of objective visual and ocular surface assessments in future Digital Eye Strain research.

5.3 Confounding factors and individual susceptibility

Multiple sources of confounding and effect modification are likely to influence observed associations between screen exposure and Digital Eye Strain symptoms in pandemic-era studies. Differences in age, refractive correction, baseline ocular surface status, device type, and home learning conditions may substantially modify symptom expression and, if unmeasured, act as important confounders in observational analyses [3,19,27,29].

Notably, many studies did not systematically account for pre-existing dry eye disease or ocular surface vulnerability, despite growing evidence that intensive digital screen exposure is associated with dry eye-related symptoms even in young adult populations [24,39,42]. Failure to distinguish baseline ocular surface status may therefore inflate associations between screen exposure and DES symptoms or obscure differential susceptibility within study populations. Similarly, uncorrected or undercorrected refractive errors and binocular vision anomalies may substantially increase symptom burden during prolonged near work and function as effect modifiers rather than independent risk factors. If not measured and adjusted for, these visual characteristics may contribute to overestimation of screen-related effects in symptom-based observational studies [1-2,6,18].

Another persistent methodological challenge is the difficulty in disentangling educational from recreational screen exposure during lockdown periods. Academic screen time frequently co-occurred with elevated leisure-related device use, resulting in cumulative daily exposure that cannot be attributed to remote learning alone [10-11,14]. This overlap likely contributes to inconsistencies across reports and limits the ability to quantify the independent contribution of remote learning to Digital Eye Strain symptom development [3,13].

5.4 Mechanistic interpretation in the context of existing frameworks

From a mechanistic perspective, symptom patterns reported during periods of intensive remote learning are consistent with established Digital Eye Strain and ocular surface frameworks. Key pathways include reduced blink rate, increased frequency of incomplete blinks, tear film instability, and heightened evaporative stress during sustained visually demanding tasks [2,7,20,23,40].

Importantly, these mechanisms were well documented prior to the COVID-19 pandemic in studies of video display terminal use, supporting the interpretation that pandemic-related remote learning primarily intensified pre-existing screen-related visual stressors rather than introducing a novel ocular condition [2,20-21]. The pandemic context therefore represents an amplification of known exposure-response pathways, driven by increased duration, continuity, and task-driven nature of near visual demands.

Recent TFOS frameworks further conceptualise the digital environment as a lifestyle-level exposure influencing ocular comfort and tear film homeostasis over time, rather than as an episodic or situational risk factor [31]. Within this framework, remote learning can be viewed as a specific exposure context embedded within a broader secular trend of increasing digital visual demands, rather than as an isolated or transient driver of Digital Eye Strain.

5.5 Broader context and implications

The broader pandemic context should be considered when interpreting these findings, as lockdown-related changes in daily routines, including reduced outdoor activity, prolonged indoor confinement, and altered patterns of visual behaviour, likely influenced both screen exposure and symptom perception. These factors may have contributed to residual confounding in observational datasets, particularly in studies relying on self-reported exposure and symptom measures [11,13].

Importantly, such contextual and behavioural factors were infrequently measured in a standardised or quantitative manner, limiting the ability to clearly disentangle direct screen-related effects from indirect influences related to lifestyle changes, environmental conditions, and psychosocial stressors during lockdown periods [13,17]. This limitation further complicates causal interpretation of observed associations between remote learning and Digital Eye Strain symptoms.

Overall, when considered collectively, the available evidence supports a clinically relevant association between remote learning during the COVID-19 pandemic and increased Digital Eye Strain symptom burden across multiple age groups [3,29-30]. Although causality cannot be definitively established, the consistency of findings across populations, study settings, and geographical regions underscores the need for future longitudinal studies incorporating objective measures of visual behaviour, ocular surface function, and exposure patterns to better characterise risk, individual susceptibility, and potential long-term visual health implications.

6. Conclusions

The evidence reviewed supports the interpretation that the COVID-19 pandemic did not give rise to a novel ocular condition but rather intensified pre-existing visual stressors associated with sustained digital device use. Digital Eye Strain is best understood as a functional, symptom-based condition arising from the interaction between visual behaviour, task demands, and environmental factors, rather than as a discrete ocular disease entity [2-4]. The abrupt shift to remote learning concentrated established risk pathways into prolonged, task-driven near work with reduced visual variability, limited opportunities for spontaneous visual breaks, and frequently suboptimal ergonomic conditions, thereby increasing symptom burden in susceptible individuals.

Post-pandemic studies continue to report a high frequency of Digital Eye Strain and dry eye–related complaints in educational and occupational contexts characterised by sustained screen

exposure, indicating that the underlying exposure patterns remain relevant beyond emergency remote learning periods [30,41]. This observation is consistent with contemporary TFOS frameworks, which conceptualise the digital environment as a lifestyle-level exposure influencing ocular comfort and tear film homeostasis over time rather than as an episodic or situational risk factor [31]. Within this framework, remote learning represents a concentrated exposure context that amplifies cumulative visual load, while broader digitalisation sustains the background risk.

Although the predominance of cross-sectional, self-reported data limits causal inference and precise attribution to educational screen exposure alone, the consistency of associations across age groups and settings supports the clinical relevance of Digital Eye Strain in modern learning environments. Future research benefits from longitudinal designs, clearer differentiation of educational versus recreational screen time, and the integration of objective measures of visual behaviour, ocular surface status, and visual function. In parallel, preventive strategies focused on visual hygiene, ergonomic optimisation, and appropriate refractive and binocular vision correction remain pragmatic targets for reducing symptom burden in increasingly digitalised educational systems.

Disclosure

Author Contribution:

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