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Effects of remote learning during COVID-19 lockdown on children's visual health: a Systematic Review.

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Complete List of Authors:	Cortés-Albornoz, María ; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences Ramírez-Guerrero, Sofía; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences Rojas-Carabali, William; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences de-la-Torre, Alejandra; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences Talero-Gutiérrez, Claudia; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences

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Authors names: María C. Cortés-Albornoz[1], Sofía Ramírez-Guerrero[1]; William Rojas-Carabali[1]; Alejandra de-la-Torre[1]; Claudia Talero-Gutiérrez[1*]

Author affiliations: 1. Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences, Universidad del Rosario, Bogotá.

Corresponding author: Claudia Talero-Gutiérrez, Kra 24#63C-69. Escuela de Medicina- Quinta de Mutis (Bogotá, Colombia), +573158959271, claudia.talero@urosario.edu.co

Author notes:

María C. Cortés-Albornoz, MD.: https://orcid.org/0000-0003-0733-5105, mariacam.cortes@urosario.edu.co

Sofía Ramírez-Guerrero: https://orcid.org/0000-0001-8927-8284, sofia.ramirezg@urosario.edu.co

William Rojas-Carabali, MD: https://orcid.org/0000-0002-9976-8989, warcinvest@gmail.com

Alejandra de-la-Torre, MD., PhD.: https://orcid.org/0000-0003-0684-1989, alejadelatorre@yahoo.com

Claudia Talero-Gutiérrez MD.: orcid.org/0000-0003-1601-5015

Abstract:

Objective: Increased exposure to digital devices for online classes increases susceptibility to visual impairments, particularly among school students exposed to e-learning strategies. This study aims to identify the impact of remote learning due to COVID-19 lockdown in children's visual health.

Methods: A systematic review was conducted using Scopus, PubMed, and ScienceDirect databases. Eligible articles included cross-sectional, case-control, and cohort studies, case series, and case reports, as well as those published in English, Spanish, or French, from the year 2020 onwards. Articles excluded were different study designs, published before 2020, studies focused on the adult population, and those evaluating children with genetic syndromes.

Results: A total of 19 articles were included with previous quality assessments following the Joanna Briggs checklist. Risk of bias assessment was applied using the NIH quality assessment tool for before-after studies, the Hoy et al. tool for prevalence studies, the Murad MH et al. tool for case reports/case series, and the Newcastle-Ottawa Scale for cohort studies. Overall, the main ocular effects found were refractive errors, accommodation disturbances, and visual symptoms (dry eye syndrome and asthenopia).

Conclusion: Before the pandemic started, there was evidence of the relationship between screen time and visual impairments. However, increased dependence on digital devices for online classes has either induced or exacerbated visual disturbances in children exposed to remote learning during the COVID-19 lockdown.

PROSPERO registration number CRD42022307107

Keywords: COVID-19, lockdown, remote learning, distance education, screen time, vision, myopia, children.

Key questions:

What is already known on this topic:

We searched 3 databases (PubMed, ScienceDirect, and Scopus) for primary research articles published in French, English, and Spanish between 2000 and 2022. The search followed the key terms: (vision) OR (visual impairment)) OR (myopia [MeSH Terms])) AND (screen time) in areas such as neuroscience, nursing, health sciences to retrieve evidence before COVID-19 pandemic. We identified different studies that inquired screen time, video gaming, and internet use with ocular surface alterations, refractive error progression, visual fatigue, retinal microvasculature alterations among other visual consequences on children. We highlight one cohort study before pandemic that found that increased near work and computer use increased the risk of myopia, while outdoor time showed a protective effect. Myopia incidence and progression are determined by other environmental and socio-cultural factors linked to lifestyles. In 2021 a retrospective cross-sectional study from 2016 to 2017 evaluated the association of electronic device use with dry eye disease in children and found a strong association with severe meibomian gland atrophy. These studies showed that adaptation of new habits due to the increase in the use of technology could trigger changes in children's visual health worldwide.

What this study adds:

To our knowledge, this is the first systematic review that summarizes evidence about the effects of remote learning during COVID-19 lockdown on children's visual health. We assessed reported data from more than 1.1 million patients worldwide addressing five clinical conditions, including esotropia, accommodation disturbances, dry eye, asthenopia, and refractive errors, especially myopia, a highly prevalent and costly condition. Most studies demonstrate that the lifestyle and habits changes during the pandemic expose children to risk factors such as high near work time and low outdoor time, increasing the incidence and prevalence of myopia and triggering new conditions such as digital eye strain and esotropia.

How this study might affect research, practice or policy:

This study identified the most prevalent visual abnormalities in children exposed to intense digital screen time during online classes in the COVID-19 lockdown scenario. The appearance and worsening of convergence insufficiency, accommodation disturbances, refraction errors, and asthenopia represents a public health issue in the growing technological era. In accordance with previous evidence, results obtained from this systematic review highlight the importance of implementing preventive and therapeutic strategies to delay the appearance or further development of visual disturbances in children.

Introduction:

Since the World Health Organization declared a global pandemic in March 2020, COVID-19 has become the focus of governmental decisions to slow down its death toll and ameliorate its consequences. Schools, universities, and businesses have been forced to close to prevent spread, inducing a drastic change from in-person relationships to absolute digital dependence (1). Lifestyle and behavioral modifications that have emerged in response to lockdowns have affected approximately 80% of the world's student population (1).

The establishment of in-house quarantine implied a significant decrease in outdoor activities, less exposure to sunlight, and increased time spent doing near work, which predisposed individuals to visual impairments, especially among school and university students submerged into a digital learning approach (1,2). Growing dependence on e-learning and electronic devices has increased the incidence of visual fatigue, onset and progression of myopia, dry eye syndrome, irregular astigmatism, and acute concomitant esotropia, among other ocular pathologies (3).

Even before the pandemic was declared, it was estimated that by the end of the century, almost 100% of the world's population will have acquired myopia (1). During COVID-19 lockdown, the increasing need for electronic devices, digital screens, and virtual classrooms have caused previously healthy students to develop myopia, and those who already had it faced a rapid progression. Obligatory confinement, intensive near-work activities, and lower sunlight exposure lead to visual fatigue and, eventually, myopia, the most prevalent ocular impairment (3).

On the other hand, digital screen use is considered a common risk factor of dry eye syndrome (DED), characterized by the deterioration of tear film quality, which can be exacerbated by longer digital screen time (4,5). The longer the screen time, the higher the risk and the more severe the symptoms (6). Myopia and dry eye syndrome are a few examples of the consequences in visual health caused by the increasing demand on e-learning approaches to which children have been exposed from a very young age. Therefore, this systematic review aims to identify the impact of remote learning due to COVID-19 lockdown in children's visual health.

Methods

Search strategy and selection criteria

In January of 2022 a Systematic review was conducted using three online databases. The following terms were used in PubMed (https://pubmed.ncbi.nlm.nih.gov/advanced/) (((((vision) OR (visual impairment)) OR (myopia[MeSH Terms])) AND (COVID-19)) AND (lockdown)) AND (screen time). In Science direct database (https://www.sciencedirect.com/search) ((vision)OR (visual impairment) OR (myopia)) AND ((Covid-19 lockdown)) AND (screen time)). Finally in Scopus database (https://www.scopus.com) we used ALL (vision OR ("visual" AND "impairment") OR myopia AND ("Covid-19" AND "lockdown") AND ("screen" AND "time")) AND (LIMIT-TO (SUBJAREA , "MEDI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "NEUR") OR LIMIT-TO (SUBJAREA , "NURS") OR LIMIT-TO (SUBJAREA , "HEAL")) . The ID CRD42022307107 was generated in the International prospective register of systematic reviews PROSPERO.

Data collection

A total of 324 articles were retrieved, duplicates were removed, and the remaining articles were filtered by title and abstract following the Preferred Reporting Items for Systemtic Reviews and Meta-Analyses guidelines (figure 1 and Supplementary table 1). Five researchers divided into two groups screened all articles, and 26 articles were selected. At weekly meetings, authors analyzed studies, debated disagreements, and double-checked all articles following inclusion and exclusion criteria. Articles were included if they studied the effects of remote learning during COVID-19 lockdown on neurotypical children's visual health. And excluded if they (I) were published before 2020; (II) studied the effects of remote learning during COVID-19 lockdown on adult or university students' visual health; (III) participants were children with genetic syndromes or visual disability; (IV) were book chapters, editorial or opinion texts; (V) were published in languages other than Spanish, English, and French. A total of 19 articles were included and evaluated with Joanna Briggs's checklist to guarantee their quality. Additionally, risk of bias assessment was applied using The National Institutes of Health (NIH) quality assessment tool for before-after (Pre-Post) studies with no control group (7), the Hoy et al. proposed tool (8,9), the Tool for evaluating the methodological quality of case reports and case series proposed by Murad MH et al. (10) and the Newcastle-Ottawa Scale for cohort studies (7). All domains were evaluated in the tools (Supplementary table 2).

Finally, data were extracted to obtain the following information: title, authors, digital object identifier number, objective, type of study, country of the study, population (age and sample), presence of control group (age and sample), implemented test or evaluation methodology, main visual outcome, results, conclusion, and a final question: is there an effect of COVID-19 lockdown on visual health? Visual health improves, worsens, or remains the same?. All information was synthesized using qualitative and quantitative synthesis (results column). Considering the heterogeneity among studies, we create subgroups of analysis to cluster findings, for example, studies regarding dry eye disease, refractive errors, clinical symptoms, among others. All investigators participated in the data collection and synthesis.

Patient and public involvement:

This research was done without patient or public involvement. However, the findings will be shared in conferences with pediatric ophthalmologists and myopic patients who attend ophthalmological services.

Results

Articles included in the review were grouped based on the main visual outcome associated with children's vision status and progression during COVID-19 lockdown. Overall, the main ocular effects found were refractive errors (myopia), accommodation disturbances (esotropia), and visual symptoms (dry eye and fatigue) (**Table 1**). Among all studies, 14 were conducted in Asia (11-24), 2 in Europe (25,26), and 3 in America (27-29). After the risk of bias assessment, we found that all the cross-sectional studies presented a low risk of bias. The unique case series had a low risk of bias. Three of the before-and-after studies had a fair quality, and one had good quality.

Table 1: Articles related to visual outcomes and the impact of remote learning during COVID-19.

Ocular outcome		Reference
Refractive errors	Myopia	(13,15,17–22,26,28,)

Vergence disturbances	Accommodation disturbances	(11,29)
	Esotropia	(25)
Visual symptoms	Dry eye	(16,24)
	Asthenopia	(12,14,23,29)

We found 10 articles regarding refractive errors related to virtual learning during COVID -19 lockdown. Most of them studied myopia progression as the main visual outcome. Seven studies evidenced that myopia worsened throughout COVID-19 lockdown in children and teenagers between 5 to 18 years old (13,15,17,18,20–22). One study showed a significant decrease in spherical equivalent refraction (SER) in children with hyperopia and emmetropia (26). Interestingly, a study evaluating axial length in myopic children undergoing orthokeratology did not find any change in myopia progression during lockdown (19). Furthermore, one study focused on children's risk factors and behavioral changes due to COVID-19 lockdown and its relationship with myopia found that all children had changes in near-work time, electronic device use, and outdoor time. However, myopic children had a significantly lower daily light exposure than non-myopic (28). Monthly myopia progression during COVID-19 lockdown was reported to be -0.074 D/month, which correlates to an annual progression in 2020 of -0.71 ± 0.46 D (13,18). SER was estimated in several studies. In 2020, the mean SER in myopic children and teenagers was between −1.94 ± 2.13 D and −2.7 ± 1.21 D being significantly lower than in 2019 (−1.64 ± 5.49 D and −1.99 ± 1.04 D, p: <0.001) (17,18). In the same way, a significant decrease in the mean SER of hyperopic and emmetrope children was found in 2019 and 2020 to be 0.66 ± 2.03 D (2019) and 0.48 ± 1.81 D (2020) with a p ≤ 0.001 (26). Finally, studies comparing virtual learning during

COVID-19 lockdown as an exposure risk factor found a higher incidence of myopia in exposed children ($p < 0.01$) (20-22).

Additionally, three studies reported accommodation and vergence dysfunction secondary to near work and increased screen-use time (11,25,29). Two studies focused on binocular accommodation in a total of 156 children, from 10 to 17 years old, reported a significant increase in the Convergence Insufficiency Symptom Survey (CISS) after exposure to longer screen time during online classes (11,25,29). The other study reported 4 cases of children with acquired concomitant esotropia and vergence abnormalities secondary to excessive use of digital devices (11,25,29).

On the other hand, emerging visual symptoms were identified in six studies whose population ranged from 8 to 20 years old. They all reported worsening of visual symptoms such as impaired vision, asthenopia, dryness, scratchiness, headache, eye redness, eye strain, and light sensitivity, among others (12,14,16,23,24,29).

Overall results based on qualitative data synthesis showed a negative effect of COVID-19 lockdown on visual health in children. Only one of the articles included did not show a deleterious impact on visual impairment (19).

Discussion

Refractive errors:

COVID-19 lockdown impacted children and teenagers' behavior and daily life, resulting in increased digital time, near work, and decreased outdoor time (30). It is estimated that close to

1.37 billion students worldwide have changed to a digital or e-learning school modality (30). These factors have been related to myopia incidence and progression (30). First, the relationship between near work, especially near reading, and myopia has been well studied even before the pandemic, as stated in The Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error Study(30,31). Second, several studies have focused on screen time and its association with myopia development (30,32,33). Third, outdoor time has been considered a protective factor against myopia onset. He et al. showed a 23% reduction in myopia incidence after 40 minutes of outdoor time (30,34).

During COVID-19, Mirhajianmoghadam et al. assessed subjective and objective measures in 14 myopic and 39 non-myopic children in the USA during 2020 (28). Initially, parents completed the University of Houston Near Work, Environment, Activity, and Refraction survey in three sessions. The first session corresponded to questions related to summer 2020, while the COVID-19 pandemic. The second session was regarded as a typical school period before COVID-19, and a third session corresponded to a typical summer period before COVID-19. Later, an actigraph device measured children's physical activity, sleep, and ambient illumination (time spent outdoors) for 10 days. Results showed that all children had less time outdoors during COVID-19 summer than before lockdown summers and an increase in daily electronic device use. Furthermore, myopic children had less daily light exposure (183.6 ± 39.3 lux) and less time outdoors (0.2 hours per day) during COVID-19 compared to non-myopic children (279.5 ± 23.5 lux, P = 0.04)(28).

Some previous studies have proposed that increased digital use time is associated with decreased time spent outdoors and retina impaired dopamine release, normally stimulated by daylight exposure. This suppresses axial expansion of the eye, preventing myopia progression (35,36). For example, Wu et al. reported that children who spent more than 11 hours a week outdoors had a 53% decrease in myopia progression (37). And Ip et al. reported an increased incidence of progression in children living in apartment buildings compared to those living in detached houses (38). And Xu et al. found that students' online time was significantly positively associated with increased myopia incidence and progression (21). However, other studies have not shown this correlation (18). Aslan et al. reported that myopia advancement in 2020 was mainly slow (0.31 ± 0.2 D) in most of the children evaluated (49 subjects), followed by moderate proregression on 45 children (0.82 ± 0.14 D). However, this study found no correlation with digital time use or glasses use (18). Yet, myopia progression and digital time use relationship are still under investigation.

Moreover, Mirhajianmoghadam et al. and Aslan et al.'s results supported findings that evaluated myopia progression due to the COVID-19 lockdown. For example, Chang et al. compared myopic progression before, during, and after COVID-19 lockdown in a 44,187-student population in China, assessing the non-cycloplegic autorefraction and the SER (13). Four evaluation rounds separated by 6 months during 2019 and 2020 indicated a transitory accelerated myopic progression in children that reversed after lockdown. Mean SER during pre-pandemic was -0.030 D/month, later during lockdown mean SER was -0.074 D/month and during post COVID 19 lockdown, was 0.016 D/month, accordingly to a myopic proportion of 48% (before lockdown), 45.2% (before lockdown) , 73.7% (shortly after lockdown) and 67.9% (after lockdown) during round 1, 2, 3 and 4 respectively. Authors considered accommodative spasms and structural changes related to restricted outdoor time, increased screen time, and limited indoor space as the leading causes of the progression. Moreover, younger children were at a higher risk of myopic progression during lockdown due to more pronounced lifestyle changes related to less light exposure and dopamine levels (13).

This matches with Wang et al., who reported a substantial decrease in the SER, especially for children aged 6 (−0.32 D), 7 (−0.28 D), and 8 (−0.29 D) years, p-value: <0.05 (15). With an earlier development of myopia in girls. The prevalence of myopia appeared to be approximately 3 times higher in 2020 than in other years for children aged 6 years, 2 times higher for children aged 7 years, and 1.4 times higher for those aged 8 years. That leads to the hypothesis that younger children are more sensitive to environmental changes than older (15). Furthermore, Wang et al. reported a prevalence of Myopia of 39.27% in primary school students, 73.39% in junior school, and 84.89% in high school students, identifying a 2020 increase rate of myopia among teenagers (55.02%) compared to 2019 (44.64%) (17).

Interestingly, Lv et al. investigated the potential impacts of home confinement on myopia progression from the perspective of axial length growth in children applying orthokeratology treatment (19). They found a monthly axial length growth of 0.023 ± 0.019 mm/month, 0.018 ± 0.021 mm/month, and 0.014 ± 0.016 mm/month before, during and after home confinement, respectively. However, the monthly axial length growth after and before confinement was not significantly different (P = 0.333), while age was negatively associated with the axial length growth rate during confinement in myopic children (19). This coincides with the findings of a previous meta-analysis that suggested that orthokeratology decreased the rate of myopia progression in children (39).

Conversely, Alvarez-Peregrina et al. did not find an increase in the prevalence of myopic children between 2019 and 2020 (26). However, they encountered that the percentage of hyperopes decreased, and the percentage of emmetropes increased ($p < 0.001$). The average SE value in 2019 was +0.66 ± 2.03 D, compared to +0.48 ± 1.81 D in 2020 ($p \leq 0.001$). This decrease was significant in children of 5 years old. Additionally, 47% (CI 95%: 45–50) of children decreased the amount of time spent outdoors ($p < 0.001$). Children who spent more time outdoors had higher SE in both cases: pre and post confinement ($p < 0.001$ and $p = 0.049$) (26). Even though Alvarez-Peregrina et al.'s results did not demonstrate a myopia progression, it is concerning to identify that the reduction of SER is a strong predictor factor of myopia in emmetropes and hyperopes children, as analyzed in WePrOM study (40).

Accommodation and vergence disturbances:

The longer duration of digital device use, the more accommodative effort is required, and consequently, increasing asthenopia symptoms and accommodation and vergence dysfunction. Mohan et al. studied the effects of online classes during the COVID-19 pandemic, considering the time spent during online classes and other digital devices such as TV, video games, and smartphones. They evidenced that 36 out of 46 children were symptomatic for convergence insufficiency, according to the CISS survey, followed by an optometrist's and pediatric ophthalmologist's evaluation. However, children exposed to classes of less than 4 hours/day registered fewer symptoms than those who attended online classes for more than 4 hours every day. Furthermore, near exophoria, near point convergence, positive fusional weakness, and accommodation excess were also reported higher in children exposed to longer online classes (11).

Similarly, Hamburger et al. evaluated ocular symptoms in 110 children who attended virtual school during the COVID-19 pandemic and found out 61% of the children reported a significant increase in convergence insufficiency as evidenced by a higher CISS score after online classes (29).

On the other hand, Vagge et al. reported four cases of children between 4 and 16 years old who developed acute acquired concomitant esotropia after intense digital device use during the COVID-19 lockdown (25). All of them experienced acute onset of diplopia after more than 8 hours a day spent on digital screens. The ophthalmologic examination reported manifest esotropia from 20 to 35 prism diopters (PD) at far and near distances in all four patients. Two out of the four presented bilaterally cycloplegic refraction of +1.00 to +2.00 diopter sphere. One of them presented cycloplegic refraction of -2.50 in the right eye and -2.25 in the left eye, and one of the four presented -0.5 bilaterally (25). Some studies suggest that digital-induced esotropia can be associated with excessive application of near vision, as well as a dynamic activation of medial rectus muscles when exposed to longer periods of digital screen time that affect the near vision triad [accommodation-convergence reflex: convergence of both eyes, contraction of the ciliary muscle resulting in a change of lens shape (accommodation), and pupillary constriction (25,41,42).

Visual symptoms

COVID-19 lockdown and remote learning has increased digital device use and consequently has precipitated a rise in dry eye symptoms and asthenopia. Hamburger et al. reported a significant increase in asthenopia symptoms before and after online classes with predominating symptoms such as discomfort, fatigue, and impaired vision. Moreover, an increased asthenopia score was identified in more than half of the children evaluated (29). Likewise, Li et al. identified a positive association between screen time and risk of asthenopia in approximately 25,000 students from 8 to 20 years old, attributing higher risks of asthenopia to conditions such as myopia, astigmatism, and mechanical factors like greater distance from the screen (23).

Elhusseiny et al. reported a significant increase in symptoms such as dryness, grittiness, and scratchiness associated with prolonged exposure to digital screens for education and leisure purposes in 403 children between 10 to 18 years (16). Similarly, Mohan et al. identified longer screen time during COVID-19 lockdown compared to pre-COVID era in 217 children, of which almost half attended online classes (12). Specifically, more than a third of the children evaluated used digital devices for over 5 hours a day, and 50.23% manifested dry eye syndrome with itching and headache as the most predominant symptoms.

Gupta et al. evaluated 654 students between 5 to 18 years old using the Rasch-based Computer-Vision Symptom Scale (14). The authors reported a significant increase in average digital device exposure, more frequently smartphone use for more than 5 hours/day. Also, children's visual symptoms were eye redness, eye strain, blurred vision, light sensitivity, and heaviness of eyelids (14). Furthermore, Li et al. identified a higher risk of computer vision syndrome in children with myopia with and without correction, presence of astigmatism, fewer outdoor activities, and prolonged screen time (24).

The relationship between digital screen time and dry eye syndrome had already been described in both adults and children, even before the COVID-19 global pandemic (43–46). Changes in blinking dynamics and ocular surface abnormalities are some of the consequences that arise from intense screen time exposure. Regarding ocular surface measures, longer screen time can decrease blinking frequency and completeness, resulting in reduced tear break-up time and tear volume, as well as changes in tear lipid composition (4,47). This means that the longer the exposure to digital devices, the more deterioration of tear film quality, and the higher the risk of developing dry eye symptoms (4).

Conclusions:

The changes in habits and lifestyles worldwide derived from the COVID-19 pandemic have severely impacted children's eye health. Ophthalmologists must know the effect that virtual learning has had on the pediatric population to identify and treat these diseases early. In addition, countries around the world must implement public health strategies to mitigate these impacts, especially in diseases as common and costly as myopia. Additionally, further studies are required to evaluate the long-term impact generated by the health conditions that started during the pandemic and could have a chronic course.

Contribution

Conceptualization, M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G.; methodology, M.C.C.-A., S.R-G., W.A.R-C, and C.T.-G.; investigation M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G; resources, M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G; data curation, M.C.C.-A., S.R-G., and C.T.-G.; writing—original draft preparation M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G.; writing—review and editing M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G.; supervision, A.d.-l.-T and C.T.-G. All authors have read and agreed to the published version of the manuscript

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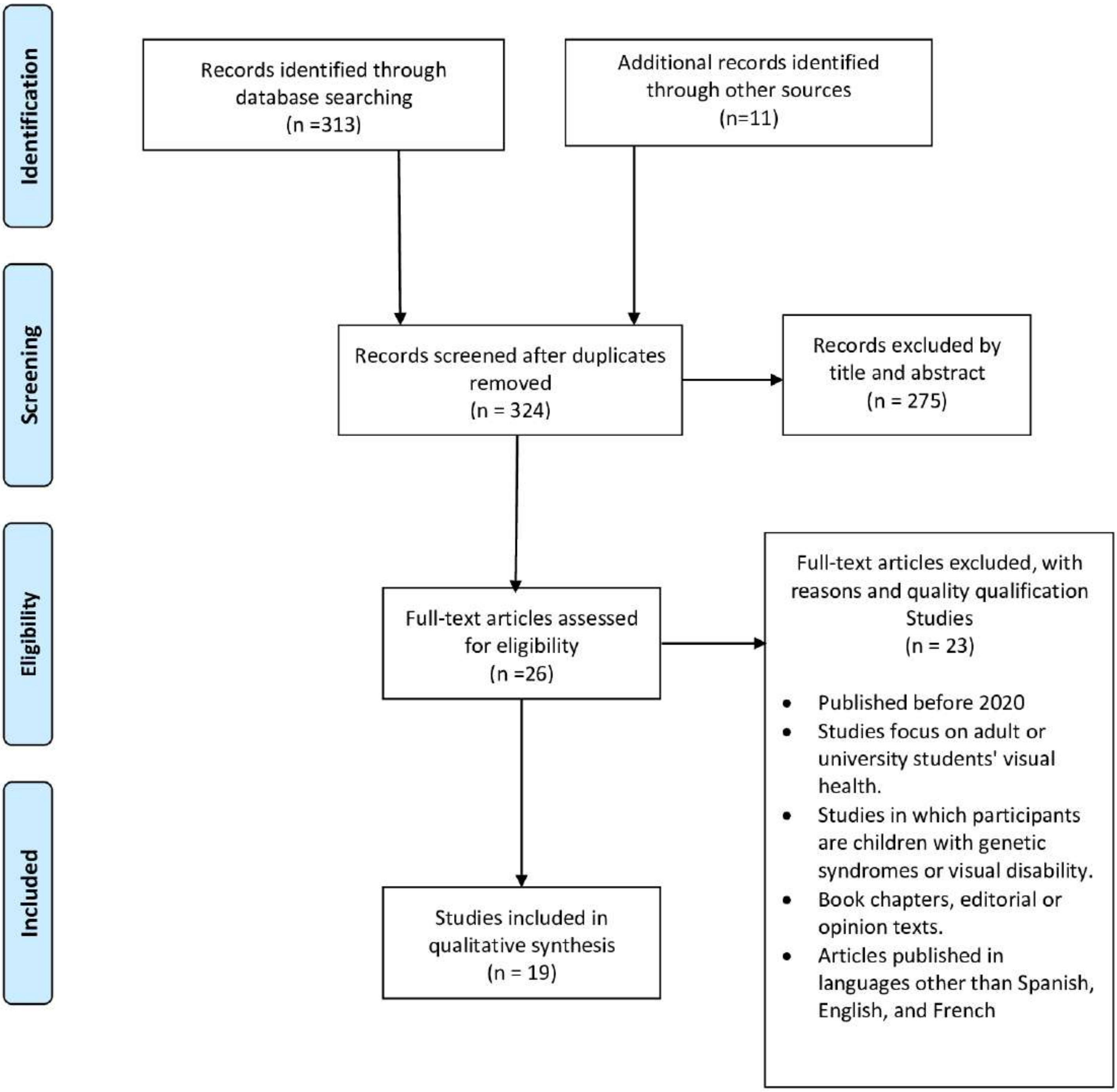
Figure Legend:

Figure 1- PRISMA Flow Diagram

PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Supplementary table 1: PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	2 Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3, 4: Key questions 5: Introduction
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	6
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	7
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	6
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	6
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	7, 8
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	7, 8
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	7, 8
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	N.A
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	7, Supplemental table 1
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	N.A

Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	7, 8
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	7
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	8
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	8
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	8
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N.A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Supplemental table 1
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N.A

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	8-10
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	7
Study characteristics	17	Cite each included study and present its characteristics.	8-10
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	7, Supplementary table 1
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N.A
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	8, Supplementary table 1

	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N.A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N.A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N.A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N.A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Supplementary table 1
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	10-17
	23b	Discuss any limitations of the evidence included in the review.	N.A
	23c	Discuss any limitations of the review processes used.	N.A
	23d	Discuss implications of the results for practice, policy, and future research.	17
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	3
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	3
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N.A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	18
Competing interests	26	Declare any competing interests of review authors.	18
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	18

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

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Supplementary Table 2: Risk of bias assessment

Risk of bias assessment of cross-sectional studies using the Hoy et al. proposed tool.

Article	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8	Question 9	Question 10	Summary on the overall risk of study bias
Relationship between screen time and dry eye symptoms in pediatric population during the COVID-19 pandemic.	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Impact of COVID-19 Home Confinement in Children's Refractive Errors	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Binocular accommodation and vergence dysfunction in children attending online classes during the COVID-19 pandemic: digital eye strain in kids (DESK) study-2	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Objective and subjective behavioral measures in myopic and non-myopic children during the covid-19 pandemic	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
The visual consequences of virtual school: acute eye symptoms in healthy children	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Impact of E-schooling on digital eye strain in Coronavirus Disease Era: A survey of 654 students	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	Low risk

Prevalence and risk factor assessment of digital eye strain among children using online elearning during the COVID-19	(LOW RISK)	(HIGH RISK)	(LOW RISK)	(HIGH RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	Moderate risk High risk
pandemic: Digital eye strain among kids (DESK study-1)											
Progression of Myopia in School-Aged Children after COVID-19 Home Confinement	NO (HIGH RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk

Interpretation: Low risk: 0-4 (No:High risk), Moderate risk: 5-7 (No:High risk), High risk 8-10 (No:High risk)

Risk of bias assessment for before-and-after studies using NIH tool.

Article	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8	Question 9	Question 10	Question 11	Question 12	Quality Rating
Comparison of Myopic Progression before, during, and after COVID-19 Lockdown 10.1016/j.ophtha.2021.03.029	YES	NO	YES	CD	NR	YES	YES	NR	NO	YES	YES	YES	Good Fair Poor
Survey on the Progression of Myopia in Children and Adolescents in Chongqing During COVID-19 Pandemic	YES	YES	YES	YES	YES	YES	YES	NR	YES	YES	NO	YES	Good Fair Poor
The effect of home education on myopia progression in children during the COVID-19 pandemic	YES	YES	NR	YES	CD	YES	YES	NR	YES	YES	NO	YES	Good Fair Poor
	YES	YES	NR	NR	CD	YES	YES	NR	CD	YES	NO	YES	Good

The impact of COVID-19 home confinement on axial length in myopic children undergoing orthokeratology													Fair Poor
COVID-19 Quarantine Reveals That Behavioral Changes Have an Effect on Myopia Progression. 10.1016/j.ophtha.2021.04.001	YES	YES	YES	YES	YES	YES	YES	NR	YES	YES	CD	YES	Good Fair Poor
Contribution of Total Screen/Online-Course Time to Asthenopia in Children During COVID-19 Pandemic via Influencing Psychological Stress	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	Good Fair Poor
Prevalence of Self-Reported Symptoms of Computer Vision Syndrome and Associated Risk Factors among School Students in China during the COVID 19 Pandemic	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES		Good Fair Poor

Interpretation: Good: 10 or more YES; Fare: 6 or more YES; Poor: 5 or less YES Abbreviations:

CD: Cannot Determine; NR: Not reported.

Risk of bias assessment of case series using the Murad MH et al. proposed tool.

Article	Selection	Ascertainment		Causality				Reporting
	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8
Acute Acquired Concomitant Esotropia From Excessive Application of Near Vision During the COVID-19 Lockdown	YES	YES	YES	YES	NA	NA	NO	YES

Risk of bias assessment of cohort studies using the NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE

Article	Selection				Comparability	Outcome			Overall
	Question 1	Question 2	Question 3	Question 4	Question 1	Question 1	Question 2	Question 3	
The Impact of Study-atHome During the COVID19 Pandemic on Myopia Progression in Chinese Children	1 Star. Truly representative of the average primary schools in Fuxing District, Handan, Hebei, China children	1 Star. Drawn from the same community as the exposed cohort	1 Star. Secure record (eg medical records and clinical evaluations)	0 Star.	1 Star. Study controls for not exposed to exposure factors (study at home)	1 Star. Confirmation of the outcome by reference to secure records and self report	1 Star. Yes: 6 months Assessment at baseline (July 2019), at the first follow-up (January 2020) and at the second follow-up (August 2020	0 Star. No statement	6 Stars.
Rates of Myopia Development in Young Chinese Schoolchildren During the Outbreak of COVID-19	1 Star. somewhat representative of the average children in the community. (Especifically, young school children)	1 Star. Drawn from the same community as the exposed cohort	1 Star. Secure record (eg medical records and clinical evaluations)	1 Star. They described the percentages of patients without the autocome at baseline.	1 Star. Study controls for grade.	1 Star. Confirmation of the outcome by reference to secure records.	1 Star. 3 measurements in 3 years.	1 Star Subjects lost to follow up unlikely to introduce bias - small number lost - < 20 % follow up.	7 Stars.

Effects of remote learning during the COVID-19 lockdown on children's visual health: a Systematic Review

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-062388.R1
Article Type:	Original research
Date Submitted by the Author:	24-May-2022
Complete List of Authors:	Cortés-Albornoz, María ; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences Ramírez-Guerrero, Sofía; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences Rojas-Carabali, William; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences de-la-Torre, Alejandra; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences Talero-Gutiérrez, Claudia; Universidad del Rosario, Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences
Primary Subject Heading:	Ophthalmology
Secondary Subject Heading:	Health policy
Keywords:	COVID-19, PAEDIATRICS, Paediatric ophthalmology < OPHTHALMOLOGY

Title: Effects of remote learning during the COVID-19 lockdown on children's visual health: a Systematic Review

Author names: María C. Cortés-Albornoz[1], Sofía Ramírez-Guerrero[1]; William Rojas-Carabali[1]; Alejandra de-la-Torre[1]; Claudia Talero-Gutiérrez[1*]

Author affiliations: 1. Neuroscience Research Group (NEUROS) and Centro Neurovitae, School of Medicine and Health Sciences, Universidad del Rosario, Bogotá

Corresponding author: Claudia Talero-Gutiérrez, Kra 24#63C-69. Escuela de Medicina y Ciencias de la Salud- Quinta de Mutis (Bogotá, Colombia), +573158959271, claudia.talero@urosario.edu.co

Author notes:

María C. Cortés-Albornoz, MD: https://orcid.org/0000-0003-0733-5105, mariacam.cortes@urosario.edu.co

Sofía Ramírez-Guerrero: https://orcid.org/0000-0001-8927-8284, sofia.ramirezg@urosario.edu.co

William Rojas-Carabali, MD: https://orcid.org/0000-0002-9976-8989, warcinvest@gmail.com

Alejandra de-la-Torre, MD, PhD: https://orcid.org/0000-0003-0684-1989, alejadelatorre@yahoo.com

Claudia Talero-Gutiérrez, MD: orcid.org/0000-0003-1601-5015, claudia.talero@urosario.edu.co

Word count: 3.713

ABSTRACT

Objectives: Increased exposure to digital devices as part of online classes increases susceptibility to visual impairments, particularly among school students taught using e-learning strategies. This study aimed to identify the impact of remote learning during the COVID-19 lockdown on children's visual health.

Design: Systematic review using the PRISMA guidelines

Data sources: Scopus, PubMed, and ScienceDirect databases from the year 2020 onwards

Eligibility Criteria: We included cross-sectional, case-control, and cohort studies, case series, and case reports, published in English, Spanish, or French, that approached the effects of remote learning during the COVID-19 lockdown on visual health in neurotypical children.

Data extraction and synthesis: We included a total of 19 articles with previous quality assessments using the Joanna Briggs checklist. Risk of bias assessment was applied using National Institutes of Health (NIH) quality assessment tool for before-after studies with no control group, the tool developed by Hoy et al. to assess cross-sectional studies, the Murad et al. tool to evaluate the methodological quality of case reports and case series, and the Newcastle-Ottawa Scale for cohort studies.

Results: All but one study reported a deleterious impact of the COVID-19 lockdown on visual health in children. Overall, the most frequently identified ocular effects were refractive errors, accommodation disturbances, and visual symptoms such as dry eye and asthenopia.

Conclusions: Increased dependence on digital devices for online classes has either induced or exacerbated visual disturbances, such as rapid progression of myopia, dry eye and visual fatigue symptoms, and vergence and accommodation disturbances, in children who engaged in remote learning during the COVID-19 lockdown.

PROSPERO registration number CRD42022307107

Keywords: Children; COVID-19; Distance education; Lockdown; Remote learning; Myopia; Screen time; Vision.

STRENGTHS AND LIMITATIONS

- A systematic review was conducted in three different databases, studies were filtered following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines.
- Analyzed studies approached the effects of remote learning during the COVID-19 lockdown on visual health in children.
- To facilitate comparison, eligible studies were clustered according to the main ocular effects evaluated, including refractive errors (myopia), accommodation disturbances (esotropia) and visual symptoms (dry eye and fatigue).
- We used quality assessment guidelines and specific risk of bias assessment tools for each study design included.
- Heterogeneous methods used in each study, including both subjective and objective measures, limits precise comparisons between them.

INTRODUCTION

Since the World Health Organization declared a global pandemic in March 2020, COVID-19 has become the focus of governmental decisions aimed at protecting the public and limiting the death toll. Schools, universities, and businesses have been forced to close to prevent the spread of the virus, limiting in-person relationships and substantially enhancing our digital dependence. The lifestyle and behavioral modifications that have emerged in response to the lockdowns have affected approximately 80% of the world's student population [1, 2].

The establishment of in-house quarantine led to a significant decrease in the amount of time spent engaged in outdoor activities, reduction in exposure to sunlight, and increase in time spent doing near work. These factors can enhance the risk of visual impairments, especially among school and university students encouraged to adopt a digital learning approach[3]. A growing dependence on e-learning and electronic devices has increased the incidence of visual fatigue, the onset and progression of myopia, dry eye, irregular astigmatism and acute concomitant esotropia among other ocular pathologies[4].

Even before the COVID-19 pandemic, an estimated 22.9% of the global population had myopia [5]. During the COVID-19 lockdown, the increased need for electronic devices, digital screens, and virtual classrooms might have caused previously healthy students to develop myopia, and faster progression in those who already had impaired vision. Obligatory confinement, intensive near work activities, and decreased exposure to sunlight can lead to visual fatigue, and may also enhance the risk of myopia, the most prevalent ocular condition[4].

Digital screen use is considered a common risk factor for dry eye, characterized by the deterioration of tear film quality. The risk of dry eye and symptom severity can be exacerbated by increased digital screen time[6,7,8]. Myopia and dry eye are potential visual health consequences associated with the increasing demand for children to engage in e-learning, which often starts at a very young age. To address this in the present systematic review, we sought to identify the impact of remote learning during the COVID-19 pandemic on visual health in school-age children.

METHODS

Search strategy and selection criteria

In January 2022, we conducted a systematic review using three online databases. We used the following terms in PubMed: (https://pubmed.ncbi.nlm.nih.gov/advanced/) (((((vision) OR (visual impairment)) OR (myopia [MeSH Terms])) AND (COVID-19)) AND (lockdown)) AND (screen time); ScienceDirect: (https://www.sciencedirect.com/search) ((vision) OR (visual impairment) OR (myopia)) AND ((Covid-19 lockdown)) AND (screen time)); and Scopus: (https://www.scopus.com) ALL (vision OR ("visual" AND "impairment") OR myopia AND ("Covid-19" AND "lockdown") AND ("screen" AND "time")) AND (LIMIT-TO (SUBJAREA, "MEDI") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "NEUR") OR LIMIT-TO (SUBJAREA, "NURS") OR LIMIT-TO (SUBJAREA, "HEAL")). The ID CRD42022307107 was generated in the PROSPERO international prospective register of systematic reviews.

Data collection

A total of 326 articles were initially retrieved. Duplicates were removed, and the remaining articles were filtered by title and abstract following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Figure 1 and Supplementary Table 1). Five researchers divided into two groups screened all of the articles, and 28 were selected for study inclusion. At weekly meetings, the authors analyzed the studies, debated disagreements, and double-checked all of the articles according to the inclusion and exclusion criteria. Articles were included if they described studies on the effects of remote learning during the COVID-19 lockdown on visual health in neurotypical children. They were excluded if they (I) were published before 2020; (II) studied the effects of remote learning during the COVID-19 lockdown on visual health in adults or university students; (III) assessed children with genetic syndromes or visual disabilities; (IV) were book chapters, editorials, or opinion pieces; (V) were published in languages other than Spanish, English, and French. Following this procedure, a total of 21 articles were included. These were evaluated using Joanna Briggs's checklist to guarantee study quality. Additionally, we conducted a risk of bias assessment using several tools. First, we used the National Institutes of Health (NIH) quality assessment tool for before-after (Pre-Post) studies with no control group [9]. This instrument evaluates 12 major components with response options of yes/no/not applicable/cannot determine/not reported and gives a final quality rating of good, poor, or fair depending on the overall item response [9]. Second, we used the tool developed by Hoy et al. to assess cross-sectional studies by categorizing the article bias as low-, moderate-, or high-risk according to responses to 10 questions[10, 11]. Third, we used the tool proposed by Murad et al. to evaluate the methodological quality of case reports and case series. This tool appraises the selection, ascertainment, causality, and reporting bias of each article and makes an overall judgment about the methodology based on the responses to eight questions[12]. Finally, we used the Newcastle-Ottawa Scale for cohort studies to assess the selection, comparability, and outcome bias of the article by applying a qualitative star scale[9]. All domains evaluated using these tools can be found in **Supplementary Table 2**.

Finally, we extracted data to obtain the following information: title, authors, digital object identifier number, objective, type of study, country in which the study was conducted, population (age and sample), presence of control group (age and sample), implemented test or evaluation methodology, main visual outcome, results, conclusion, and answers to the question "Did the COVID-19 lockdown impact visual health (improvement, deterioration, no change)? All information was synthesized using qualitative and quantitative synthesis (see the Results section). Considering the heterogeneity among studies, we created subgroups for analysis, for example, studies regarding dry eye, refractive errors, clinical symptoms, and other clusters. All investigators participated in the data collection and synthesis.

Patient and public involvement:

This research was done without patient or public involvement. However, the findings will be shared at conferences attended by pediatric ophthalmologists and myopic patients who access ophthalmological services.

RESULTS

We grouped the articles included in the review based on the main visual outcome associated with vision status and changes in vision in children during the COVID-19 lockdown. Overall, the main ocular effects observed were refractive errors (myopia), accommodation disturbances (esotropia) and visual symptoms (dry eye and fatigue) (**Table 1**). Among the studies, 16 were conducted in

Asia[13-28], 2 in Europe[29, 30], and 3 in America [31-32]. The risk of bias assessment revealed that all of the cross-sectional studies and case series had a low risk of bias. Three of the before-and-after studies had fair quality, and one had good quality.

Table 1: Articles related to visual outcomes and the impact of remote learning during the COVID-19 pandemic.

Title	Authors	Year	Type of study	Country of the study	Results	¿ Is there an effect of COVID-19 lockdown on visual health?
Comparison of Myopic Progression before, during, and after COVID-19 Lockdown	Chang, P. et al.	2021	Before and after study	China	Proportions of myopia and high myopia Round 1: 48.0% and 1.3% Round 2 : 53.2% and 1.9% Round 3: 73.7% and 2.8% Round 4: 67.9% and 2.7% Mean rDSER: Period 1: -0.030 D/month (95% confidence interval [CI], e0.031 to e0.029 D/month), Period 2 (Lockdown): -0.074 D/month (95% CI, e0.075 to e0.074 D/month), Period 3: 0.016 D/month (95% CI, 0.015e0.018 D/month).	Worsen
Impact of COVID-19 Home Confinement in Children's Refractive Errors	Alvarez-Peregrina, C. et al.	2021	Cross-sectional	Spain	Spherical equivalent: Average value in 2019: +0.66 ± 2.03 D Average value in 2020: +0.48 ± 1.81 D Children lifestyle during confinement: 56% changed the amount of time spent outdoors (CI 95%: 53–58) 47% (CI 95%: 45–50) of the cases, this time decreased (p < 0.001).	Worsen

					Children near vision during confinement: 49% changed the amount of time they spent doing near-distance activities (CI 95%: 47–52). 44% (CI 95%: 41–46; p < 0.001) of the children increased near-distance activities. 42% of the children changed the amount of time they spent with electronic devices (CI 95%: 40–45). 39% (CI 95%: 37–42; p < 0.001) of cases increase electronic use. Children who spent more time outdoors had higher SE in pre and post confinement (p < 0.001 and p = 0.049).	
Objective and subjective behavioral measures in myopic and non-myopic children during the covid-19 pandemic	Mirhajianmoghadam, H. et al.	2021	Cross-sectional	United States	1. SUBJECTIVE MEASURES: -Significant interaction between session and day of the week. -Time outdoors: 2hours less during the 2020 summer of COVID-19 compared to typical summer before COVID-19. No significant differences between refractive error groups (P = 0.20). -Daily electronic device use: increased on weekdays and weekends during COVID-19 (7.3 ± 0.6 and 7.9 ± 0.7 hours) compared to a typical summer (4.9 ± 0.5 and 6.1 ± 0.5 hours, P < 0.001) and to a typical school periods (3.4 ± 0.3 and 5.4 ± 0.5 hours, P < 0.001) 2. OBJECTIVE MEASURES: -During COVID-19: myopic children had lower daily light exposure (183.6 ± 39.3 lux) than non-myopic children (279.5 ± 23.5 lux, P = 0.04) (P = 0.09).	Unclear
Progression of Myopia in School-Aged Children after COVID-19 Home Confinement	Wang, J. et al.	2021	prospective cross-sectional	China	Mean SER: -Annual screenings from 2015 to 2019: stable for all age groups. -SER decreased in 2020 compared with 2015-2019 in children aged 6 (−0.32 D), 7 (−0.28 D), and 8 (−0.29 D) years. Prevalence of myopia: -2020: 21.5% at 6 years, 26.2% at 7 years, and 37.2% at 8 years. -2015-2019: 5.7% at 6 years in 2019, 16.2% at 7 years in 2018, and 27.7% at 8 years in 2018.	Worsen
Survey on the Progression of Myopia in Children and Adolescents in Chongqing During COVID-19 Pandemic	Wang, W. et al.	2021	Before and after study	China	Myopia prevalence among teenagers: -2019: 44.62% -2020: 55.02% . Average progression rate: 10.49%. Spherical equivalent: -2019:−1.64 ± 5.49 D -2020: −1.94 ± 2.13 D Myopia percentage was 84.89% in high school, 73.39% in junior school and 39.27% in primary.	Worsen
The effect of home education on myopia progression in children during the	Aslan, F. et al.	2021	Before and after study	Turkey	Mean duration spent in front of the screen was 5.77 ± 1.34 h/day The mean SE of the refractive values was: -2016: −1.14 ± 0.66 D	Worsen

COVID-19 pandemic					-2017: −1.47 ± 0.82 D -2018: −0.45 ± 0.91 D -2019: −1.99 ± 1.04 D -2020: −2.7 ± 1.21 D Myopic progression of 0.71 ± 0.46 D in 2020 The mean myopic progression 2020: - Overall: 0.71 ± 0.46 D - In children who spent time outside in the daylight for 2 h a day: 0.55 ± 0.42 D - In children with less outside time: 0.82 ± 0.45 D (p = 0.003) The myopia progression in 2020 was slow (0.31 ± 0.2 D) in 42.6% of subjects, moderate (0.82 ± 0.14 D) in 39.1% and rapid in 1.42 ± 0.29 D in 18.3%. No correlation was found between the 2020 progression and the daily digital device use.	
The impact of COVID-19 home confinement on axial length in myopic children undergoing orthokeratology	Lv, H. et al.	2022	Before and after study	China	Monthly axial length growth: -After confinement: 0.023 ± 0.019 mm/month -During confinement: 0.018 ± 0.021 mm/month, negatively related (P = 0.002). -Before confienement: 0.014 ± 0.016 mm/month The monthly axial length growth after and before confinement was not significantly different (P = 0.333)	Remains the same
The Impact of Study-at-Home During the COVID-19 Pandemic on Myopia Progression in Chinese Children	Dandan, M. et al.	2022	Cohort	China	Myopia progression: p < 0.001. -In exposed group:−0.83 ± 0.56 D -In Control grouo: −0.28 ± 0.54 D In the exposed group, children had a larger change in myopia progression in the follow-up period (−0.83 ± 0.56 D) compared to the baseline period (−0.33 ± 0.46 D; p < 0.001). Increment on near work time from 2.96 ± 1.05 hours per day to 4.33 ± 1.04 hours per day (p < 0.001) during COVID-19. Decrease on outdoor activities from 1.84 ± 1.43 hours per day to 0.98 ± 1.01 hours per day (p < 0.001) during COVID-19.	Worsen
COVID-19 Quarantine Reveals That Behavioral Changes Have an Effect on Myopia Progression.	Liangde, X. et al.	2021	Before and after study	China	Myopia prevalence: -June 2019: 52.89% (95% confidence interval [CI], 52.79%-52.99%) -December 2019: 53.9%(95% CI, 53.79%-54.01%). -June 2020: 59.35% (95% CI, 59.24%-59.46%) Increase in myopia prevalence: -Grades 1 to 6: 8.54% -Grades 7 to 12: 4.32% Half-year incidence rate of myopia: -Before COVID-19: 8.5% -After COVID-19: 13.62% (P < 0.001)	Worsen
Rates of Myopia Development in	Yin, H. et al.	2021	Cohort	China	The mean AL was 0.11 mm (95% CI, 0.05-0.16).	Worsen

Young Chinese Schoolchildren During the Outbreak of COVID-19					Exposed group: -Myopic shift of SER: 0.36 D (95% CI, 0.32-0.41; P < .001) and 0.08 mm (95% CI, 0.06-0.10; P < .001) greater AL elongation. -Incidence of myopia: 7.9% (95% CI, 5.1-10.6; P < .001) higher. -Prevalence of myopia: 219 of 1054 students (20.8%) was 7.5% (95% CI, 4.3-10.7) higher than in the nonexposure group (141 of 1060 students [13.3%])	
Impact of online classes and home confinement on myopia progression in children during COVID-19 pandemic: Digital eye strain among kids (DESK) study 4	Mohan, A. et al.	2022	Cross-sectional	India	Myopia progression resport: -Before COVID-19: 45.9% of participants -During the COVID-19: 62.5% of participants.	Worsen
Acute Acquired Concomitant Esotropia From Excessive Application of Near Vision During the COVID-19 Lockdown	Vagge, A. et al.	2021	Case series	Italy	1. A 4-year-old girl with ACE of 35 prism diopters managed with glasses. She used the tablet around 8h/d 2. A 16-year-old boy with ACE of 30 prism diopters managed with Fresnel prism. Computer 8h/d 3. A 16-year-old boy with ACE of 20 prism diopters managed with Fresnel prism. Computer 10h/d 4. An 8-year-old girl with ACE of 25 prism diopters managed conservatively. She used the tablet around 8h/d	Worsen
Binocular accommodation and vergence dysfunction in children attending online classes during the COVID-19 pandemic: digital eye strain in kids (DESK) study-2	Mohan, A. et al.	2021	Cross-sectional	India	Mean CISS scores: -In children using devices less than 4/hours/day: 21.73 ± 12.81 -In children using digital devices for 4 hours/day or more: 30.34 ± 13.0 for (P = .019). Mean values of near exophoria (P = .03), NFV (P = .02), NRA (P = .057), and AA (P = .002) Spearman correlation between CISS score and the duration of online classes: weak linear association (coefficient rs = 0.39, P = .007).	Worsen
The visual consequences of virtual school: acute eye symptoms in healthy children	Hamburger, J.,L. et al.	2022	cross-sectional	United States	CISS score: -Before school: Mean of 5.17 and median of 4 -After school: Mean of 9.82 and a median of 7.5 (mean change, 4.65; median change 2; P < 0.001) -Linear regression analysis of change in total CISS score from before to after school versus hours spent in virtual school: score increase of 1.243 per hour of virtual school. (P = 0.0282) The asthenopia score: -Before school: Mean of 1.58 and total median of 1 -After school: Mean of 2.74 and a median of 2 (mean change, 1.15, median change, 1; P < 0.001) -Linear regression analysis of change in total asthenopia score from before to after school versus actual hours spent in	Worsen

					virtual school: score increase of 0.280 per hour of virtual school. (P = 0.0807).	
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	Mohan, A. et al.	2021	Case series	India	-5/8 subjects were emmetropic, 1 myopic, 1 pseudomyiopic, 1 mild hyperopic. -Average use of device: 4.6 + 0.7 hours per day at an average of 5.5 inches from the screen. -Average angle deviation for near with corrected vision in esotropia: 48.1 ± 16.4 PD - 7/8 children reported horizontal diplopia.	Worsen
Relationship between screen time and dry eye symptoms in pediatric population during the COVID-19 pandemic	Elhusseiny, A.M. et al.	2021	Cross-sectional	Egypt	m-SPEED questionnaire score: -Pre-COVID-19: 0.83 ± 2.04 (P < 0.001). -COVID-19 2020: 3.9 ± 4.53 --> higher in urban areas (4.68 ± 4.87) vs. rural areas ((2.97 ± 3.69) (P<0.001). Screen time: -Male sex: associated with greater ST (Mean difference of 0.6 ± 0.31 h per day (P=0.047)). -Development of DED :in association with prolonged ST.	Worsen
New Indicator of Children's Excessive Electronic Screen Use and Factors in Meibomian Gland Atrophy	Cremers, S.,L. et al.	2021	Cross-sectional	United States	CHESUD: -Four or more hours: 86% OF MGA cases -Eight or more hours: 50% Severe MGA related to: - Less outdoor time - Higher meibography scores (<0.01) CHESUD positively association with the increase in combined meibography scores (OR: 2.81; 95% confidence interval [CI], 1.66 to 4.77)	Worsen
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)	Mohan, A. et al.	2021	Cross-sectional	India	During the COVID-19: -Mean duration of digital device use: 3.9 ± 1.9 h -Percentage of children using devices for >5 hr: 36.9% Before COVID: -Mean duration of digital device use: 1.9 ± 1.1 h -Percentage of children using devices for >5 hr: 1.8% Survey report: -Eyesight worsened because of the online classes: 49.76% - Overall prevalence of DES: 50.23%.	Worsen
Impact of E-schooling on digital eye strain in Coronavirus Disease Era: A survey of 654 students	Gupta, R. et al.	2021	Cross-sectional	India	Asthenopic and dry eye symptoms: -Heaviness of eyelids:79.7%, Eye redness: 69.1%, Eye strain: 68.2%, Blinking: 57.8%, Blurred vision: 56.9%, Light sensitivity: 56%, Stinging: 47.1%, and Burning: 46.3%. Digital device use: < 4hours: 30 (12.5%) children, 5-6hours: 13 (6.6%) children,	Worsen

					> 6 hours: 4 (2.3%) children, Had not reported any AS (P = 0.001) Computer vision syndrome score: CVS score was statistically significantly lower in the 5–7-year group vs. 11–16 year group [P = 0.004].	
Prevalence of Self-Reported Symptoms of Computer Vision Syndrome and Associated Risk Factors among School Students in China during the COVID 19 Pandemic	Li, R. et al.	2021	cross-sectional	China	53% used glasses, 47% myopia, 2.9% myopia, 2.1% hyperopia, 13% astigmatism, 0.8% amblyopia, 0.7% anisometropia, 1.5% strabismus, 2.5% conjuctivitis, 1.7% previous eye surgery. Mean screen time 4.6h/day, 1.2 h/day on outdoor activities, 9.9 h/day on sleep. Self-reported symptoms: 13% double vision, 48% itching, eye dryness. -Mild intensity: 1.4% colored halos around objetcs, 8.8% eye dryness, 0.3% double vision, 3.2% neck or shoulder pain -Moderate intensity: 1.3% colored halos around objetcs, 7.8% dry eyeness -Severe intensity: 0.3% double vision, 2.7% neck or shoulder pain or feeling sight worsening	Worsen
Contribution of Total Screen/Online-Course Time to Asthenopia in Children During COVID-19 Pandemic via Influencing Psychological Stress	Lin, J., Z. et al,	2021	cross-sectional	China	63.1% had myopia, 36% had astigmatism, and 12.1% reported asthenopia. Students with asthenopia had longer screen/online-course time and less daily rest time. A 100-h increment were associated with an increased 9% risk of asthenopia [odds ratio (OR) = 1.09] and 11% (OR = 1.11).	Worsen

We identified 11 articles that examined refractive errors related to virtual learning during the COVID-19 lockdown. Most of these examined myopia progression as the main visual outcome. Eight studies reported that myopia worsened throughout the COVID-19 lockdown in children and teenagers between 5 and 18 years old[15, 17, 19, 21, 22, 23, 24, 27]. One study reported a significant decrease in spherical equivalent refraction (SER) in children with hyperopia and emmetropia (see Table 2. Glossary) [30]. Interestingly, a study evaluating axial length in myopic children undergoing orthokeratology (see Table 2. Glossary) did not find any change in myopia progression after lockdown [21]. Furthermore, one study focused on risk factors and behavioral changes during the COVID-19 lockdown in terms of myopia found that all children had changes in near-work time, electronic device use, and outdoor time. However, myopic children had a significantly lower levels of daily light exposure compared with non-myopic children[32]. The monthly extent of myopia progression during the COVID-19 lockdown was reported to be –0.074 D/month, which corresponds to an annual progression in 2020 of –0.71 ± 0.46 D[15, 20]. Furthermore, rapid myopia progression was reported in a sample of 133 school students. Specifically, the percentage of children with reported annual progression for whom progression was rapid increased from 10.5% before to 45.9 % during the pandemic [27]. SER was estimated in several studies. In 2020, the mean SER in myopic children and teenagers was between −1.94 ± 2.13 D and −2.7 ± 1.21 D, and this was significantly lower than in 2019 (−1.64 ± 5.49 D and −1.99 ± 1.04 D, $p < 0.001$)[19, 20]. Similarly, there was a significant decrease in the mean SER of hyperopic and emmetropic children from 2019 to 2020, i.e., 0.66 ± 2.03 D (2019) and 0.48 ± 1.81 D (2020), respectively, $p \leq 0.001$[30]. Finally, studies examining virtual learning during the COVID-19 lockdown as an exposure risk factor found a higher incidence of myopia in children who engaged in virtual learning ($p < 0.01$)[22-24].

Four studies reported accommodation and vergence dysfunction (see Table 2. Glossary) secondary to near work and increased screen-use time[13, 26, 29, 33]. Two studies focused on binocular accommodation in a sample of 156 children aged 10 to 17 years old and reported a significant increase in convergence insufficiency symptom survey (CISS) scores after exposure to longer screen time during online classes[11, 29]. The other two were case series of children who developed acquired concomitant esotropia and vergence abnormalities secondary to the excessive use of digital devices[27, 29].

Emerging visual symptoms were identified in six studies with populations ranging from 8 to 20 years old. The studies reported worsening of visual symptoms such as vision impairment, asthenopia, dryness, scratchiness, headache, eye redness, eye strain, and light sensitivity, among others[14, 16, 18, 25, 26, 33].

Overall, the results of qualitative data syntheses showed a negative effect of the COVID-19 lockdown on visual health in children. Only one of the articles included did not report a deleterious impact of the lockdown on vision[21].

DISCUSSION

Most of the studies included in this systematic review showed some degree of worsening in visual health in children exposed to virtual learning strategies during the COVID-19 lockdown. The majority of the articles focused on myopia development and progression, and reported a faster onset and progression following the beginning of the lockdown. Also, prolonged exposure to screens was associated with worsened ocular symptoms such as eye strain, blurred vision, and redness, as well as an increase in the rate of dry eye, which is traditionally considered to be uncommon in the pediatric population.

Refractive errors

The COVID-19 lockdown impacted the behavior and daily life of children and teenagers, resulting in increased digital time, near work, and decreased outdoor time[34]. It is estimated that close to 1.37 billion students worldwide switched to a digital or e-learning school modality during the lockdown[34]. These changes have been related to an increase in myopia incidence and progression[34]. First, the relationship between near work, especially near reading, and myopia was well established before the COVID-19 pandemic, as stated in the Collaborative Longitudinal Evaluation Of Ethnicity And Refractive Error Study[34, 35]. Second, several studies have focused on screen time and its association with myopia development[34, 36, 37]. Third, outdoor time has been considered a protective factor against myopia onset. He et al. showed a 23% reduction in myopia incidence after 40 minutes of outdoor time daily[34, 38].

During the COVID-19 pandemic in 2020, Mirhajianmoghadam et al. assessed subjective and objective measures in 14 myopic and 39 non-myopic children in the USA[32]. Initially, parents completed the University of Houston Near Work, Environment, Activity, and Refraction survey in three sessions. The first session included questions related to summer 2020, which was during the COVID-19 pandemic. The second session served to collect data about a typical school period before the COVID-19 pandemic, and the goal of the third session was to collect data about a typical summer period before the pandemic. Later, the investigators used an actigraph device to measure physical activity, sleep, and ambient illumination exposure (time spent outdoors) in children for 10 days. The results indicated that all of the children spent less time outdoors during the summer of the pandemic (2020) compared with before the lockdown and showed an increase in daily electronic device use. Furthermore, myopic children had less daily light exposure (183.6 ± 39.3

lux) and spent less time outdoors (0.2 hours per day) during COVID-19 compared with non-myopic children (279.5 ± 23.5 lux, P = 0.04)[32].

The authors of several previous studies have proposed that increased time spent using digital devices is associated with decreased time spent outdoors and impaired retinal dopamine release, which is normally stimulated by daylight exposure. This suppresses axial expansion of the eye, preventing myopia progression[39, 40]. For instance, Wu et al. reported that children who spent more than 11 hours a week outdoors had a 53% decrease in myopia progression[41], and Ip et al. reported an increased incidence of progression in children living in apartment buildings compared with those living in detached houses[42]. Additionally, Xu et al. found that the amount of time spent online was significantly positively associated with an increased incidence of myopia and progression in students[23]. However, not all studies have shown this correlation[20]. Aslan et al. reported that myopia advancement in 2020 was mainly slow (0.31 ± 0.2 D) in most of the children evaluated (49 subjects), followed by moderate progression in 45 children (0.82 ± 0.14 D). The authors found no correlation between myopia progression and digital device time or glasses use[20]. Thus, the relationship between myopia progression and digital device use requires further investigation.

The studies by Mirhajianmoghadam et al. and Aslan et al. support findings of myopia progression during the COVID-19 lockdown. For example, Chang et al. compared myopic progression before, during, and after the COVID-19 lockdown in 44,187 students in China by assessing non-cycloplegic autorefraction and the SER[15]. Four evaluation rounds separated by 6 months during 2019 and 2020 indicated a transitory period of accelerated myopic progression in children that reversed after the lockdown. The mean SER during the pre-pandemic assessment was –0.030 D/month, shortly after the lockdown was –0.074 D/month, and later during the lockdown was 0.016 D/month. The proportion of myopic participants was 48% before the lockdown, 45.2% at a second assessment before the lockdown, 73.7% shortly after the lockdown, and 67.9% later after the lockdown during round 1, 2, 3, and 4, respectively. The authors considered the influence of accommodative spasms and structural changes related to restricted outdoor time, increased screen time, and limited indoor space to be the leading cause of the progression. Moreover, they found that younger children were at a higher risk of myopic progression during the lockdown because their lifestyle changes were strongly associated with reduced light exposure, and accordingly, reduced retinal dopamine levels[15].

This is concordant with the findings of Wang et al., who reported a substantial decrease in the SER after COVID-19 home confinement, especially for children aged 6 (−0.32 D), 7 (–0.28 D), and 8 (−0.29 D) years, p-value < 0.05[17]. Furthermore, they found myopia development to occur earlier in girls than boys. The prevalence of myopia appeared to be approximately 3 times higher in 2020 than in other years for children aged 6 years, 2 times higher for children aged 7 years, and 1.4 times higher for those aged 8 years. This led the authors to hypothesize that younger children are more sensitive to environmental changes than older children[17]. Furthermore, Wang et al. reported a prevalence of myopia of 39.27% in primary school students, 73.39% in junior school students, and 84.89% in high school students, identifying an increase in the rate of myopia among teenagers in 2020 (55.02%) compared with that in 2019 (44.64%)[19].

Lv et al. investigated the potential impacts of home confinement on myopia progression from the perspective of axial growth length in children undergoing orthokeratology treatment [21]. They found a monthly axial growth length of 0.023 ± 0.019 mm/month, 0.018 ± 0.021 mm/month, and 0.014 ± 0.016 mm/month before, during, and after home confinement, respectively. However, the monthly axial growth length before confinement was not significantly different from that after confinement ($P = 0.333$), although age was negatively associated with the axial length growth rate during confinement in myopic children [21]. This coincides with the findings of a previous meta-analysis that suggested that orthokeratology decreases the rate of myopia progression in children [43].

In contrast, Alvarez-Peregrina et al. did not find an increase in the prevalence of myopia among children between 2019 and 2020[30]. However, they observed that the percentage of hyperopes decreased, and the percentage of emmetropes increased ($p < 0.001$). The average SE value in 2019 was +0.66 ± 2.03 D, compared with +0.48 ± 1.81 D in 2020 ($p \leq 0.001$). This decrease was significant in children aged 5 years. Additionally, 47% (CI 95%: 45–50) of children spent less time outdoors in 2020 versus 2019 ($p < 0.001$). Children who spent more time outdoors had higher SE values both pre- and post-confinement ($p < 0.001$ and $p = 0.049$)[26]. Even though Alvarez-Peregrina et al. did not demonstrate myopia progression, a reduction in SER is a strong predictive factor for myopia in emmetropic and hyperopic children, as indicated by the Wenzhou Medical University Essilor Progression and Onset of Myopia (WePrOM) study[44].

Accommodation and vergence disturbances

A longer duration of digital device use requires more accommodative effort, and consequently, increases the chance of asthenopia symptoms and dysfunctional accommodation and vergence (see Table 2. Glossary). Mohan et al. studied the effects of online classes during the COVID-19 pandemic, and considered the time spent in online classes and using digital devices such as TV, video game systems, and smartphones. According to the CISS survey, followed by evaluations by an optometrist and pediatric ophthalmologist, 36 out of 46 examined children had symptoms of convergence insufficiency. However, children who attended online classes for less than 4 hours/day exhibited fewer symptoms than those who attended online classes for more than 4 hours every day. Furthermore, near exophoria, near point convergence, positive fusional weakness, and accommodation excess were more frequent in children exposed to longer online classes[13].

Similarly, Hamburger et al. evaluated ocular symptoms in 110 children who attended virtual school during the COVID-19 pandemic. They found that 61% of the children reported a significant increase in convergence insufficiency, as evidenced by a higher CISS score after attending online classes[33].

Vagge et al. reported four cases of children between 4 and 16 years old who developed acute acquired concomitant esotropia after intense digital device use during the COVID-19 lockdown[29]. All of the children experienced acute onset diplopia (see Table 2. Glossary) after more than 8 hours per day spent looking at digital screens. Ophthalmologic examination reported manifest esotropia from 20 to 35 prism diopters (PD) at far and near distances in all four patients. Two out of the four children presented bilaterally cycloplegic refraction of +1.00 to +2.00 diopter sphere. One of them presented cycloplegic refraction of –2.50 in the right eye and –2.25 in the left eye, and another presented –0.5 bilaterally[29]. Some studies have suggested that digital device-induced esotropia is associated with excessive application of near vision, as well as dynamic activation of the medial rectus muscles when exposed to longer periods of digital screen time. This may affect the near vision triad, i.e., the accommodation-convergence reflex: convergence of both eyes, contraction of the ciliary muscle resulting in a change of lens shape (accommodation), and pupillary constriction[29, 45, 46].

Visual symptoms

The increase in digital device use associated with the COVID-19 lockdown and remote learning has precipitated a rise in dry eye symptoms and asthenopia. Hamburger et al. reported a significant increase in asthenopia symptoms after online classes with discomfort, fatigue, and impaired vision as dominant symptoms. Moreover, an increased asthenopia score was identified after online classes in more than half of the children evaluated [33]. Likewise, Li et al. identified a positive association between screen time and the risk of asthenopia in approximately 25,000 students aged 8 to 20 years old, and attributed a higher risk of asthenopia to conditions such as myopia, astigmatism, and mechanical factors like distance from the screen[25].

Elhusseiny et al. reported a significant increase in symptoms such as eye dryness, grittiness, and scratchiness associated with prolonged exposure to digital screens for education and leisure purposes in 403 children aged 10 to 18 years[18]. Similarly, Mohan et al. identified longer screen time during the COVID-19 lockdown compared with the pre-COVID era in 217 children, of which almost half attended online classes[14]. More than a third of the evaluated children used digital devices for over 5 hours a day, and 50.23% manifested dry eye with itching and headache as predominant symptoms.

Gupta et al. evaluated 654 students between 5 and 18 years old using the Rasch-based Computer-Vision Symptom Scale[16]. The authors reported a significant increase in average digital device exposure during confinement, particularly smartphone, which was greater than 5 hours/day. Visual symptoms in the children were eye redness, eye strain, blurred vision, light sensitivity, and

182 heaviness of eyelids [16]. Furthermore, Li et al. identified a higher risk of computer vision
183 syndrome in children with myopia with and without correction, astigmatism, fewer outdoor
184 activities, and prolonged screen time[26].

185 The relationship between digital screen time and dry eye has already been described in both adults
186 and children, as well as before the global COVID-19 pandemic[47-50]. Changes in blinking
187 dynamics and ocular surface abnormalities are some of the consequences that arise from intense
188 screen exposure. Regarding ocular surface measures, longer screen time can decrease blinking
189 frequency and completeness, resulting in reduced tear break-up time and tear volume, as well as
190 changes in tear lipid composition[6, 51]. This means that a longer exposure to digital devices can
191 enhance the deterioration of tear film quality, and thus increase the risk of developing dry eye
192 symptoms[6].

193 A main limitation of this study is the inclusion of articles with different study designs, as it is
194 difficult to compare them quantitative and qualitatively. Moreover, the evidence reported in the
195 selected studies was obtained using distinct evaluation methods, from symptom surveys to detailed
196 ophthalmologic examinations, influencing the objectiveness of the conclusions obtained. Given
197 that most of the studies were developed specifically in Asian countries, extrapolations to other
198 parts of the world should be made with caution.

199 **Conclusions**

200 The changes in habits and lifestyles as a result of the COVID-19 pandemic have severely impacted
201 eye health in children. Children attending classes as part of a remote learning strategy had more
202 rapid myopia progression, increased frequency of dry eye and visual fatigue symptoms, and
203 exhibited signs of vergence and accommodation disturbances such as acute acquired concomitant

esotropia and convergence insufficiency. Ophthalmologists, pediatricians, and general physicians should make themselves aware of the effect of virtual learning on the pediatric population to enable early identification and management of these conditions. In addition, countries around the world must implement public health strategies to mitigate the impacts of a more screen-focused life, especially with respect to conditions as common and costly as myopia. Further studies are required to evaluate the long-term impacts of such changes associated with the COVID-19 pandemic.

Contributions

Conceptualization, M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G.; methodology, M.C.C.-A., S.R-G., W.A.R-C, and C.T.-G.; investigation M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G; resources, M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G; data curation, M.C.C.-A., S.R-G., and C.T.-G.; writing—original draft preparation M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G.; writing—review and editing M.C.C.-A., S.R-G., W.A.R-C., A.d.-l.-T and C.T.-G.; supervision, A.d.-l.-T and C.T.-G. All authors have read and agreed to the published version of the manuscript.

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226 **Data availability statement:** Data collected from this study is available for sharing. Extraction
227 data are available upon request to the corresponding author.

228 **Table 2. Glossary**
229

Term	Definition
Accommodation	Contraction of the ciliary muscle resulting in a change of lens shape. (1)
Asthenopia	Subjective symptoms of ocular fatigue or eye strain. (1)
Astigmatism	Type of refractive error due to imperfection in the curvature of the eye that causes blurred distance and near vision.(2)
Cycloplegic refraction	A technique used to calculate the complete refractive error by temporarily paralyzing the ciliary muscle of the eye that aid in focusing. (1)
Diplopia	Disorder of vision in which two images of a single object are seen. (1)
Dry eye	Alteration of ocular surface homeostasis characterized by an alteration of the tear film.
Emmetropia	Refractive state of an eye in which parallel rays of light entering the eye are focused on the retina, creating an image that is perceived as crisp and in focus. (3)
Esotropia	Eye misalignment in which one eye is deviated inward, or nasally. (2)
Hyperopia	Ocular condition in which the refracting power of the eye causes light rays entering the eye to have a focal point that is posterior to the retina while accommodation is maintained in a state of relaxation. (2)
Myopia	Ocular condition in which the refracting power of the eye causes light rays entering the eye to have a focal point that is anterior to the retina while accommodation is maintained in a state of relaxation. (2)
Orthokeratology	Use of specially designed and fitted contact lenses to temporarily reshape the cornea to improve vision.(4)
Refractive errors	Type of vision problem that makes it hard to see clearly and happens when the shape of your eye keeps light from focusing correctly on your retina.(3)
Spherical equivalent refraction	Estimate of the eyes' refractive error, calculated independently for each eye. It is calculated by merging the spherical (nearsightedness or farsightedness) and cylindrical (astigmatism) refractive error components.(2)

Vergence	The turning motion of the eyeballs toward (convergence) or away (divergence) from each other. (1)

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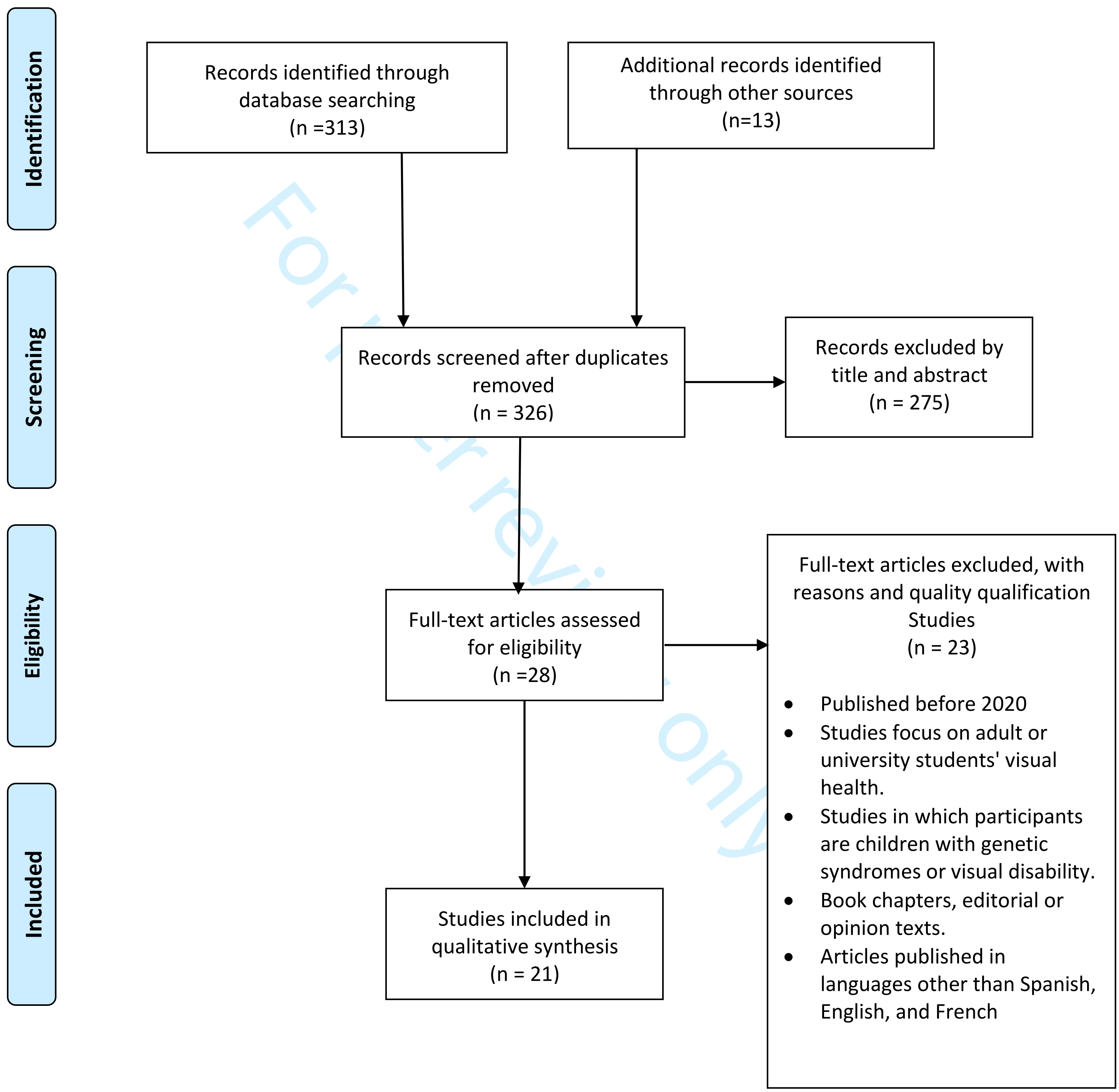
Figure Legend:

Figure 1- PRISMA Flow Diagram

PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

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Supplementary table 1: PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3, 4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	5
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	5
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5,6
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	5,6
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	5,6
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	N.A
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	6, Supplemental table 1
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	8: Table 1
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	5,6
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	5

	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	6
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	6
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	6
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N.A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Supplemental table 1
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N.A

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	8-10
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	7
Study characteristics	17	Cite each included study and present its characteristics.	8-10
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	6, Supplementary table 1
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N.A
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	6, Supplementary table 1
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N.A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N.A

	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	8: Table 1
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N.A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Supplementary table 1
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	10-17
	23b	Discuss any limitations of the evidence included in the review.	17
	23c	Discuss any limitations of the review processes used.	17
	23d	Discuss implications of the results for practice, policy, and future research.	17
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	5
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	5
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N.A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	18
Competing interests	26	Declare any competing interests of review authors.	18
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	18

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

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Supplementary Table 2: Risk of bias assessment

Risk of bias assessment of cross-sectional studies using the Hoy et al. proposed tool.

Article	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8	Question 9	Question 10	Summary on the overall risk of study bias
Relationship between screen time and dry eye symptoms in pediatric population during the COVID-19 pandemic.	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Impact of COVID-19 Home Confinement in Children's Refractive Errors	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Binocular accommodation and vergence dysfunction in children attending online classes during the COVID-19 pandemic: digital eye strain in kids (DESK) study-2	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Objective and subjective behavioral measures in myopic and non-myopic children during the covid-19 pandemic	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
The visual consequences of virtual school: acute eye symptoms in healthy children	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
Impact of E-schooling on digital eye strain in Coronavirus Disease Era: A survey of 654 students	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk
	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	Low risk

Prevalence and risk factor assessment of digital eye strain among children using online elearning during the COVID-19	(LOW RISK)	(HIGH RISK)	(LOW RISK)	(HIGH RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	(LOW RISK)	Moderate risk High risk
pandemic: Digital eye strain among kids (DESK study-1)											
Progression of Myopia in School-Aged Children after COVID-19 Home Confinement	NO (HIGH RISK)	NO (HIGH RISK)	NO (HIGH RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	YES (LOW RISK)	Low risk Moderate risk High risk

Interpretation: Low risk: 0-4 (No:High risk), Moderate risk: 5-7 (No:High risk), High risk 8-10 (No:High risk)

Risk of bias assessment for before-and-after studies using NIH tool.

Article	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8	Question 9	Question 10	Question 11	Question 12	Quality Rating
Comparison of Myopic Progression before, during, and after COVID-19 Lockdown 10.1016/j.ophtha.2021.03.029	YES	NO	YES	CD	NR	YES	YES	NR	NO	YES	YES	YES	Good Fair Poor
Survey on the Progression of Myopia in Children and Adolescents in Chongqing During COVID-19 Pandemic	YES	YES	YES	YES	YES	YES	YES	NR	YES	YES	NO	YES	Good Fair Poor
The effect of home education on myopia progression in children during the COVID-19 pandemic	YES	YES	NR	YES	CD	YES	YES	NR	YES	YES	NO	YES	Good Fair Poor
	YES	YES	NR	NR	CD	YES	YES	NR	CD	YES	NO	YES	Good

The impact of COVID-19 home confinement on axial length in myopic children undergoing orthokeratology													Fair Poor
COVID-19 Quarantine Reveals That Behavioral Changes Have an Effect on Myopia Progression. 10.1016/j.ophtha.2021.04.001	YES	YES	YES	YES	YES	YES	YES	NR	YES	YES	CD	YES	Good Fair Poor
Contribution of Total Screen/Online-Course Time to Asthenopia in Children During COVID-19 Pandemic via Influencing Psychological Stress	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	Good Fair Poor
Prevalence of Self-Reported Symptoms of Computer Vision Syndrome and Associated Risk Factors among School Students in China during the COVID 19 Pandemic	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES		Good Fair Poor

Interpretation: Good: 10 or more YES; Fare: 6 or more YES; Poor: 5 or less YES Abbreviations:

CD: Cannot Determine; NR: Not reported.

Risk of bias assessment of case series using the Murad MH et al. proposed tool.

Article	Selection	Ascertainment		Causality				Reporting
	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8
Acute Acquired Concomitant Esotropia From Excessive Application of Near Vision During the COVID-19 Lockdown	YES	YES	YES	YES	NA	NA	NO	YES

Risk of bias assessment of cohort studies using the NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE

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Article	Selection				Comparability	Outcome			Overall
	Question 1	Question 2	Question 3	Question 4	Question 1	Question 1	Question 2	Question 3	
The Impact of Study-atHome During the COVID19 Pandemic on Myopia Progression in Chinese Children	1 Star. Truly representative of the average primary schools in Fuxing District, Handan, Hebei, China children	1 Star. Drawn from the same community as the exposed cohort	1 Star. Secure record (eg medical records and clinical evaluations)	0 Star.	1 Star. Study controls for not exposed to exposure factors (study at home)	1 Star. Confirmation of the outcome by reference to secure records and self report	1 Star. Yes: 6 months Assessment at baseline (July 2019), at the first follow-up (January 2020) and at the second follow-up (August 2020	0 Star. No statement	6 Stars.
Rates of Myopia Development in Young Chinese Schoolchildren During the Outbreak of COVID-19	1 Star. somewhat representative of the average children in the community. (Especifically, young school children)	1 Star. Drawn from the same community as the exposed cohort	1 Star. Secure record (eg medical records and clinical evaluations)	1 Star. They described the percentages of patients without the autocome at baseline.	1 Star. Study controls for grade.	1 Star. Confirmation of the outcome by reference to secure records.	1 Star. 3 measurements in 3 years.	1 Star Subjects lost to follow up unlikely to introduce bias - small number lost - < 20 % follow up.	7 Stars.

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