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Systematic Review and Meta-Analysis on the Impact of COVID-19 Pandemic–Related Lifestyle on Myopia

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Purpose: To conduct a systematic review and meta-analysis to assess the effects of coronavirus disease 2019 (COVID-19) pandemic–related lifestyle on myopia outcomes in children to young adults.

Methods: A systematic search was conducted on PubMed, Embase, and the Cochrane Central Register of Controlled Trials databases (with manual searching of reference lists of reviews). Studies included assessed changes in myopia-related outcomes (cycloplegic refraction) during COVID and pre-COVID. Of 367 articles identified, 7 (6 prospective cohorts; 1 repeated cross-sectional study) comprising 6327 participants aged 6 to 17 were included. Quality appraisals were performed with Joanna Briggs Institute Critical Appraisal Checklists. Pooled differences in annualized myopic shifts or mean spherical equivalent (SE) during COVID and pre-COVID were obtained from random-effects models.

Results: In all 7 studies, SE moved toward a myopic direction during COVID (vs pre-COVID), where 5 reported significantly faster myopic shifts [difference in means of changes: −1.20 to −0.35 diopters per year, [D/y]; pooled estimate: −0.73 D/y; 95% confidence interval (CI): −0.96, −0.50; $P<0.001$], and 2 reported significantly more myopic SE (difference in means: −0.72 to −0.44 D/y; pooled estimate: −0.54 D/y; 95% CI: −0.80, −0.28; $P<0.001$). Three studies reported higher myopia (SE ≤ −0.50 D) incidence (2.0- to 2.6-fold increase) during COVID versus pre-COVID. Of studies assessing lifestyle changes, all 4 reported lower time outdoors (pre-COVID vs during COVID: 1.1–1.8 vs 0.4–1.0 hours per day, [h/d]), and 3 reported higher screen time (pre-COVID vs during COVID: 0.7–2.8 vs 2.4–6.9 h/d).

Conclusions: This review suggests more myopic SE shifts during COVID (vs pre-COVID) in participants aged 6 to 17. COVID-19 restrictions may have worsened SE shifts, and lifting of restrictions may lessen this effect. Evaluations of the long-term effects of the pandemic lifestyle on myopia onset and progression in large studies are warranted to confirm these findings.

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The authors have no conflicts of interest to declare.

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INTRODUCTION

Myopia affects over 75% of young adults living in parts of urban East and Southeast Asia.[1–4] In the United States and parts of Europe, myopia prevalence of around 35% to 52% has been reported in young adults aged 18–29 years (y).[5–8] Individuals with high myopia are susceptible to myopic maculopathy,[9] glaucoma,[10] cataracts, and retinal detachment,[9,11] By 2050, estimates suggest that around 50% and 10% of the world population will be living with myopia or high myopia, respectively.[12] Reduced outdoor activities[13,14] and higher education[15] are the major environmental risk factors for myopia.[16] Growing evidence suggests that more children with more near-work tend to be more myopic.[17–20] In addition, digital-screen time is inextricably linked to near-work and may exert an independent effect on myopia, although results have been mixed.[21,22] Parental myopia[23,24] and genetic factors[25] have also been implicated.

On December 31, 2019, the coronavirus disease 2019 (COVID-19) was first reported, leading to the declaration of a global pandemic in March 2020.[26] Many countries imposed social restrictions, in the form of citywide lockdowns, extensive home confinements, or school closures.[27] By April 2020, 151 countries worldwide have implemented countrywide or partial school closures,[28] with most countries replacing in-person lessons with intensive home-based online learning.[29] Given that these restrictions are unprecedented and may directly influence time outdoors[30] or screen time,[31,32] concerns regarding the potential effects of COVID-19 pandemic–related lifestyle on possible surges in “quarantine myopia” worldwide have been raised.[33–35] Furthermore, with COVID-19 likely persisting as a public health threat in the medium to long term, and the increasing access to and reliance on digital devices, any potential impacts on myopia may extend beyond the pandemic.[35]

Yet, to the best of our knowledge, there is a dearth of evidence-based reviews summarizing the current literature on this relevant topic of public health concern. Hence, we aimed to conduct (1) a systematic review to assess the effects of COVID-19 pandemic–related lifestyle on myopia outcomes, and (2) meta-analyses to quantify changes in cycloplegic spherical equivalent (SE) during COVID, compared with pre-COVID.

METHODS

Search Strategy

Following the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines, a systematic search was conducted on PubMed, Embase, and the Cochrane Central Register of Controlled Trials to identify potential articles published between January 1, 2019, and March 14, 2022 (date of search). No restrictions on study design or language were applied. Search terms across all fields were applied and combined using “OR” and “AND” Boolean operators: (COVID-19 OR Coronavirus) AND (myopia OR spherical equivalent OR refractive error OR axial length OR short-sighted). In addition, the reference lists of review articles were manually searched for any additional articles not captured by the electronic database search. Articles returned from the search strategy were screened for eligibility. The relevance of articles was first assessed based on titles, followed by abstracts. Subsequently, full-text articles were retrieved for a detailed assessment of their eligibility for inclusion in the review, based on the inclusion criteria.

Inclusion Criteria

Articles were eligible for inclusion if they were original research reports addressing the aim of this study. This includes articles that had evaluated the COVID-19 pandemic–related lifestyle on changes in myopia outcomes in children, teenagers, or young adults. Articles that were excluded: (1) did not present original data (eg, reviews, editorials); (2) did not report any myopia outcomes both during COVID and pre-COVID; (3) were not conducted with cycloplegic refraction data; (4) had small sample sizes of <50 participants; (5) missing information on sample sizes and statistical analyses for comparisons of myopia outcomes during COVID and pre-COVID; or (6) included a subset of participants who had received myopia treatment. Studies conducted without cycloplegic refraction data (the gold standard for refraction assessment)[36] were excluded as noncycloplegic assessments of ocular outcomes tend to result in more myopic SE and overestimate myopia, with high rates of error for emmetropic and hyperopic refractive errors, particularly in school-age children due to the strong accommodative reserves.[37–39] Where myopia prevalence is low, small amounts of pseudomyopia may significantly affect the accurate estimation of myopia prevalence[37,40] in the absence of cycloplegia.

Identification of Eligible Studies

Based on the inclusion criteria, from the 367 articles identified, 85 full-text articles were screened for eligibility, and 7 studies were eligible for inclusion in the final qualitative synthesis (Fig. 1). In addition, all 7 studies were included in meta-analyses to evaluate the changes during COVID and pre-COVID for the most reported outcome (ie, SE).

Data Extraction and Quality Appraisal of Included Studies

Data extracted from each included article were as follows: authors and publication date, location, study design, sample size, population characteristics, response or participation rates, methods for the assessments of lifestyle factors or myopia outcomes, duration of pre-COVID or during COVID periods for ocular measurements or duration between ocular measurements (either the reported mean duration of periods or the approximated mean duration between time points of measurements), and results on changes in myopia outcomes or COVID-19 pandemic–related lifestyle factors (ie, time outdoors, near-work, and screen time). Time outdoors (hours per day, [h/d]) may include outdoor activities for sports or leisure. Near-work activities may include reading and writing, crafts, and homework (using paper and pen) for school or leisure. Screen time may include using handheld electronic devices (smartphones, tablets, or other gaming devices), computers, or watching television for school or leisure.

The Joanna Briggs Institute Critical Appraisal Checklists for Analytical Cross-Sectional Studies or Cohort Studies were used for the quality appraisal of included articles.[41] One of 4 ratings was assigned to each parameter in the appraisal checklist: (1) low risk of bias (yes), (2) unclear risk of bias, (3) high risk of bias (no), or (4) not applicable. The methodological quality of articles and their limitations was described narratively. In addition, the methodological and clinical heterogeneity of included studies were examined by a qualitative description of the study design and characteristics.

Two authors (M.L. and L.X.) independently conducted the database search, screened articles based on predefined inclusion criteria, and performed data extraction and quality appraisals of included articles.

Statistical Analysis

Definitions of Periods (or Time Points) Pre-COVID and During COVID

Myopia outcomes reported by individual studies comprise 2 broad categories. Individual studies with category 1 myopia outcomes are those that have compared myopic shifts (ΔSE), axial elongation (ΔAL), or myopia incidence between 2 periods (where period 1 is pre-COVID and period 2 is during COVID). For category 1 myopia outcomes, each period had a follow-up duration of ≥ 5 months (mo). Myopic shifts in a period were defined as the change in SE in diopters (D). Axial elongation in a period was defined as the change in axial length (AL) in millimeters (mm). Myopia incidence in a period was defined as the number of new cases of myopia within the period. All pre-COVID periods or time points were dated January 2020 or earlier. Individual studies with category 2 myopia outcomes are those that have compared changes in myopia outcomes (eg, SE, myopia prevalence) between 2 time points (where time points 1 and 2 correspond to pre-COVID and during COVID time points, respectively). Category 2 myopia outcomes were differentiated from that of category 1 in that the changes in outcomes between (but not within) pre-COVID and during COVID at 2 time points were reflected, as reported time points were not feasible for assessments of changes in outcomes within each distinct period (ie, period pre-COVID or during COVID).[42,43]

Effect Estimates of Individual Studies

For individual studies, their effect estimates and corresponding 95% confidence intervals (CIs) were extracted or computed (if unreported in the original studies). For continuous myopia outcomes, the effect estimates were either

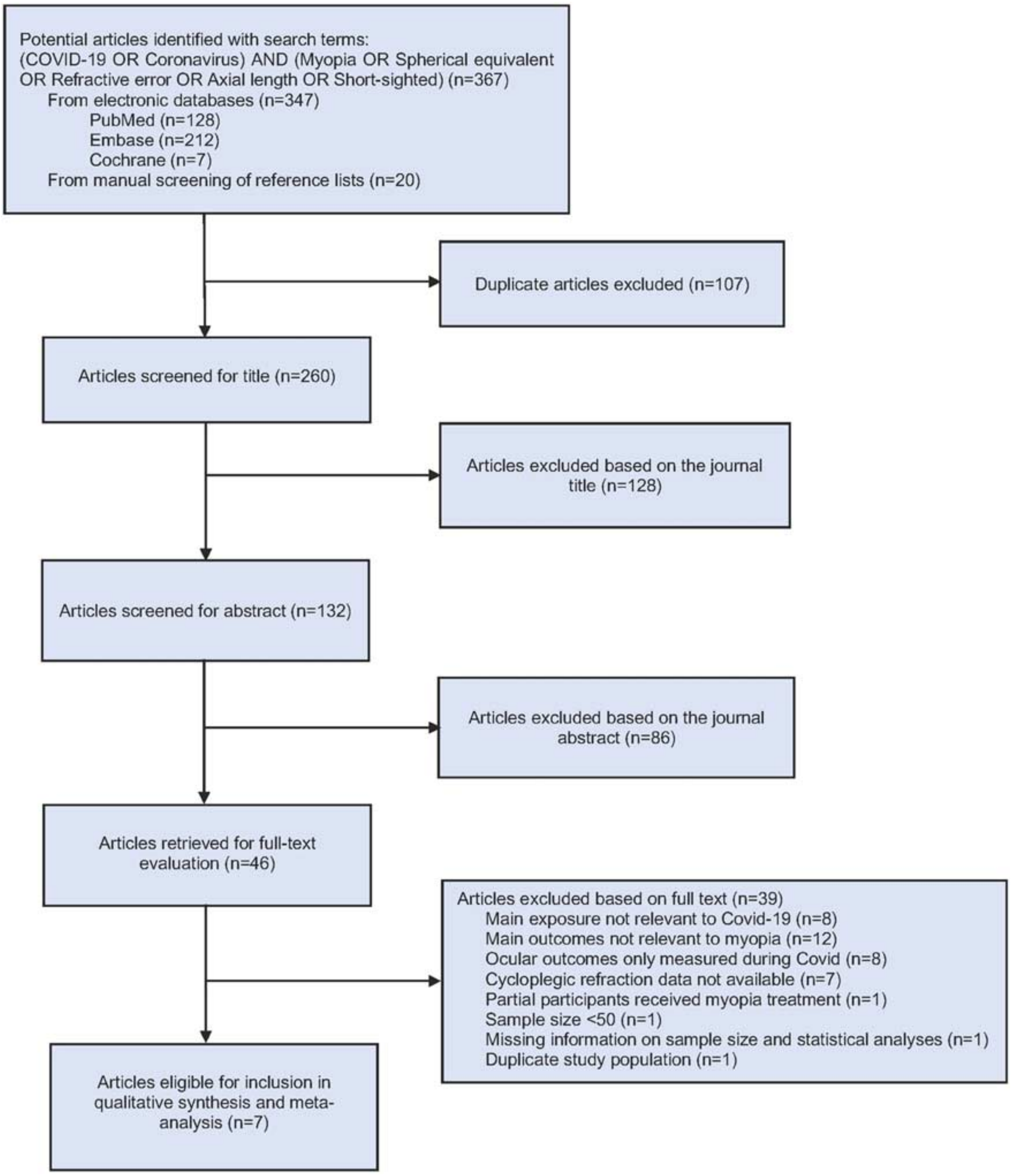

FIGURE 1. Study selection. COVID-19 indicates coronavirus disease 2019.

the difference in the means of changes between periods, or the difference in means between time points, during COVID and pre-COVID, respectively. Median and interquartile ranges were transformed to mean and SD based on the formula by Hozo et al.[44] Annualized changes in myopia outcomes (eg, ΔSE, ΔAL, myopia incidence) were extracted where available; otherwise, changes in outcomes over the specified periods in each study were extracted. If a specific myopia outcome was available at >1 time point pre-COVID (from various comparison years), the outcome dated closest to the COVID-19 pandemic was used to compute the effect estimate. For studies that did not report effect estimates of continuous myopia outcomes, these estimates were computed from the estimated mean of myopia outcomes (ie, ΔSE, ΔAL, SE, AL) during COVID and pre-COVID. For myopia incidence (or prevalence), its estimated proportion ($\hat{p}$) was assumed to be normally distributed (with standard error: $\sqrt{\hat{p}\,(1 - \hat{p})/n}$) and its effect estimates were defined as the difference in proportions during COVID and pre-COVID. The computation of effect estimates (and their standard errors) from studies with independent or paired groups [correlations (r) assumed to be 0] was based on the formulae detailed in Borenstein and colleagues.[45,46] For studies that reported annualized quantities without their standard errors, their annualized estimates and standard errors were computed using a similar approach described in the following subsection.

Meta-Analyses for Pooled Effect Estimates

SE was the only common myopia outcome reported across all 7 studies; therefore, 2 separate meta-analyses were performed to pool effect estimates that were based on either (1) the difference in annualized means of myopic shifts between the period during COVID and pre-COVID, or (2) the annualized difference in means of SEs between the time point during COVID and pre-COVID, respectively. To account for the nonuniform duration between ocular measurements across studies, studies with no reported annualized effect estimates were transformed to a 12-month scale before pooling. This transformation was performed by multiplying: (1) 12/(duration of change) and means of myopia shifts for each period (before taking the difference between periods); or (2) 12/(duration between the 2 time points) and the difference in means of SE (between time points). The standard errors of the difference in annualized means of myopic shifts from studies with independent or paired (with r assumed to be 0) groups were generated using the formulae detailed in Borenstein and colleagues.[45,46]

Effect estimates from individual studies[45] were pooled using the generic inverse variance approach in random-effects models,[47] where the between-study heterogeneity variance (τ^2)[48] was estimated using the moment estimator of DerSimonian-Laird.[49] Pooled effect estimates were presented using forest plots. Sensitivity analyses were conducted to assess the robustness of pooled effect estimates by either varying the values of r of paired groups (where r was 0.25, 0.50, or 0.75, respectively) or using nonannualized effect estimates.

Statistical heterogeneity was assessed using the I^2 statistic.[50] For models with substantial heterogeneity ($I^2 > 50\%$), individual study characteristics were explored using subgroup analyses. Publication bias was assessed by Egger test[51] for funnel plot asymmetry. P values <0.05 were considered statistically significant. Statistical analyses to compute pooled effect estimates were conducted in R, version 4.1.3.

RESULTS

Of the 7 included studies, there were 6 prospective cohort studies,[42,52–56] and 1 repeated cross-sectional study[43] (Table 1). From these 7 studies, there was a total of 6327 participants aged 6 to 17 y. Most studies were conducted in urban cities in China (6 studies),[42,52–56] and the remaining study was conducted in an urban city in Turkey.[43] There was 1 population-based study, 3 school-based studies, and 3 hospital-based studies. Across all studies, the sex composition was comparable, where approximately half (range: 48%–53%) of the participants in each study were boys (except in the only repeated cross-sectional study[43] where 35% were boys). Across 6 of 7 studies, participants were of comparable ages at baseline and within a tight age range (age range: 6 to ≤12 y; mean age range: 7.3–9.9 y). The mean SEs at baseline were different across the 7 studies, ranging from −2.25 to 1.07 D across the 7 studies (SE > −0.50 D in 3 studies[42,52,53]; SE ≤ −0.50 D in 4 studies of range −0.59 to −2.25 D[43,54,55,56]).

Quality appraisals conducted using the Joanna Briggs Institute Critical Appraisal Checklists revealed potential sources of bias: incomplete follow-up of <75%[54] or the absence of strategies to address incomplete follow-up[54]; unclear information on the use of validated questionnaires to assess changes in lifestyle factors[56] and the retrospective assessment of changes in lifestyle factors (between during COVID and pre-COVID periods) at a single time point during COVID.[54,55] Other potential risks of bias include the noncomparable duration of study periods (during COVID vs pre-COVID) in 1 study,[52] inclusion of myopic participants in 2 studies,[43,56] and unadjusted comparisons of myopia outcomes during COVID and pre-COVID in 4 studies.[42,43,55,56] However, comparisons during COVID and pre-COVID were made between paired groups (where participants served as their own control) in 5 studies, and for each of the remaining 2 studies where comparisons were made between independent groups, analyses adjusted for key confounders[52] or age-matched analyses[53] were presented.

All 7 selected studies reported at least 1 refractive error outcome measured with cycloplegic refraction (eg, myopic shifts, myopia incidence, myopia prevalence, or SE) (Table 2). Across all studies, myopia was consistently defined as SE ≤ −0.5 D. Four studies further reported ΔAL[52–55] in the periods during COVID and pre-COVID, where AL was measured using optical biometers (IOL Master)[57] across studies. In addition, 4 studies assessed changes in lifestyle factors between time points during COVID and pre-COVID (via parental or self-reports via questionnaires).[52,54–56] Reported P values and the corresponding 95% CIs of effect estimates that we had computed were concordant with regard to statistical significance (ie, $P < 0.05$).

A few other studies assessed changes in myopia outcomes between periods during COVID and pre-COVID but were excluded due to a lack of cycloplegic refraction data.[58–64] Of these studies without cycloplegic refraction data, 2 studies were prospective cohorts.[58,59] One of the 2 prospective cohorts by Xu et al[58] reported more myopic shifts (during COVID: −0.34 D vs pre-COVID: −0.23 D, $P < 0.001$) and higher myopia incidence (during COVID: 13.6% vs pre-COVID: 8.5%, $P < 0.001$) over 6-month periods during COVID (compared with pre-COVID), in 768,492 age-matched participants between 7 to 18 y from Wenzhou, China. The other cohort by Chang et al[59] reported significantly higher myopia prevalence (during COVID: 73.7% vs pre-COVID: 48.0%, $P < 0.001$) during COVID, in 29,719 participants aged 6 to 17 y from Hangzhou, China. However, cycloplegic refraction was not performed in both studies, and thus, the validity of these results may be limited.[36]

Of the 7 selected studies included in this review, 5 studies[52–56] reported significantly more myopic shifts (ΔSE) in the period during COVID, compared with pre-COVID (difference in means of changes ranging from −0.60 to −0.35 D for periods of varying duration between 5 and 12 mo). Two remaining studies[42,43] reported significantly more myopic SE at the time point during COVID,[42,43] compared with pre-COVID (difference in means ranging from −0.72 to −0.48 D for durations of around 12 to 13 mo between time points).

There was significantly higher myopia incidence (by around 2.0- to 2.6-fold) in the period during COVID (compared with pre-COVID) in 3 studies,[52,53,55] and significantly higher myopia prevalence (by around 2.6-fold) in the study by Ma et al[54] at the time point during COVID (compared with pre-COVID).

Among the 4 studies that reported ΔAL outcomes, there was significantly faster ΔAL (difference in means of changes ranging from 0.08 to 0.16 mm) in the period during COVID (vs pre-COVID) in 2 larger studies by Zhang et al[52] and Hu et al,[53] but not in the remaining 2 smaller studies ($P > 0.05$ for all) by Ma and colleagues.[54,55] In the studies by Zhang et al[52] and Hu et al,[53] where significantly faster ΔAL was reported, there were

TABLE 1. Characteristics of Studies of the Effect of the COVID-19 Pandemic–Related Lifestyle on Myopia (n = 7)

References	Study Design	Study Population	City (Country)	n	Age (y)*	Duration of Periods† or Between Time Points‡ (mo)§
Studies assessing changes in myopia outcomes in periods during COVID vs pre-COVID						
Zhang et al[52]	Prospective Cohort‖	Population-based	Hong Kong (China)	1793	7.3 ± 0.8 (pre-C) 7.3 ± 0.9 (during-C) (6–8)	38 (pre-C) 8 (during-C)¶
Hu et al[53]	Prospective Cohort‖	School-based (12 schools)	Guangzhou (China)	2114	7.8 ± 0.3 (pre-C) 7.7 ± 0.3 (during-C)	12
Ma et al[54]	Prospective Cohort	School-based (3 schools)	Handan (China)	77	8.7 ± 0.3 (8–10)	7
Ma et al[55]	Prospective Cohort	Hospital-based#	Handan (China)	208	8.9 ± 0.7 (8–10)	7
Ma et al[56]	Prospective Cohort	Hospital-based (1 hospital)	Shanghai (China)	201	9.9 ± 1.7 (7–12)	5.4 (pre-C) 5.7 (during-C)
Studies assessing myopia outcomes at time points during COVID vs pre-COVID						
Yao et al[42]	Prospective Cohort	School-based (7 schools)	Lhasa (China)	1819	7.9 ± 0.5	13
Aslan et al[43]	Repeated Cross-sectional	Hospital-based (1 hospital)	Antalya (Turkey)	115	12.1 ± 2.3 (8–17)	12

*The mean age ± SD and age range (in brackets) of participants were presented where available.

†Reported duration of each period (during COVID or pre-COVID) for the assessment of changes in myopia outcomes between these 2 periods.

‡Duration between time points during COVID and pre-COVID for the assessment of myopia outcomes between these 2 time points. The mean duration between time points was approximated based on the duration between reported study visit dates (or calendar years) for outcome measurements.

§For the assessment of changes in lifestyle factors: duration between time points during COVID and pre-COVID in the studies by Zhang et al[52] and Ma et al[56] was 8 months; in the studies by Ma and colleagues'[54,55], changes in lifestyle factors were assessed at a single time point during COVID.

‖Participants in the periods pre-COVID and during COVID were 2 independent groups in the studies by Zhang et al[52] (pre-COVID: n = 1084; during COVID: n = 709) and Hu et al[53] (pre-COVID: n = 1060; during COVID: n = 1054).

¶In the study by Zhang et al,[52] annualized changes in myopia outcomes during each period (12 mo) were reported and extracted for analysis.

#The number of hospitals included was not reported.

**Age ranges of children in Hu et al's[53] study (elementary school grades 2–3 only) and Yao et al's[42] study (elementary school grades only).

COVID-19 indicates coronavirus disease 2019; during-C, during COVID; mo, months n, sample size; pre-C, pre-COVID.

also significantly more myopic shifts (difference in means of changes ranging from −0.36 to −0.35 D) and significantly higher myopia incidence (by around 2.0- to 2.6-fold) during COVID (vs pre-COVID). Furthermore, despite null findings for ΔAL, both Ma and colleagues[54,55] reported significantly more myopic shifts (difference in means of changes ranging from −0.60 to −0.50 D, $P < 0.001$ for all) during COVID (vs pre-COVID).

Of 7 studies, 4 reported changes in lifestyle factors during COVID, compared with pre-COVID. In the study by Zhang and colleagues, there was a significant decrease in time outdoors (−0.8 h/d; 95% CI: −0.9, −0.7) and a significant increase in screen time (4.1 h/d; 95% CI: 3.8, 4.5) or near-work (4.1 h/d; 95% CI: 3.8, 4.5) during COVID (vs pre-COVID).[45] Overall, significantly lower levels of time outdoors,[52,54,55,56] but significantly higher levels of screen time[52,54,55,56] and near-work[52,54,55] were reported at the time points during COVID (vs pre-COVID). Although Ma et al[56] reported a significant decrease in near-work (by 1.1 h/d), a significant increase in screen time of 4.5 h/d ($P < 0.001$ for all) was concurrently reported during COVID (vs pre-COVID).[56] In parallel with these lifestyle changes, there were significantly more myopic shifts in all 4 studies (difference in means of changes ranging from −0.60 to −0.35 D),[52,54–56] significantly higher myopia incidence of around 2.0- to 2.4-fold,[52,55] significantly higher myopia prevalence of around 2.6-fold[54] or significantly faster ΔAL with a difference in means of changes of 0.16 mm[52] during COVID (vs pre-COVID).

Meta-analyses were performed using random-effects models for SE outcomes in all 7 studies, including 5 studies that reported changes in myopic shifts (ΔSE) between periods,[52–56] and 2 studies that reported SE between time points, during COVID and pre-COVID[42,43] (Fig. 2). In the 5 studies that reported myopic shifts (ΔSE), the pooled effect estimate (of the difference in means of changes) suggested significantly more myopic shifts (−0.73 D/y; 95% CI: −0.96, −0.50; $P < 0.001$; $I^2 = 96\%$; $\tau^2 = 0.06$) in the period during COVID (compared with pre-COVID). In the remaining 2 studies that reported SEs,[42,43] the pooled effect estimate (of the difference in means) suggested significantly more myopic SE (−0.54 D/y; 95% CI: −0.80, −0.28; $P < 0.001$; $I^2 = 70\%$; 95% CI: 0, 93; $\tau^2 = 0.03$) at the time point during COVID (compared with pre-COVID).

Exploratory analyses to identify sources of heterogeneity in the 5 studies that reported myopic shifts (ΔSE) between

TABLE 2. Results of Studies of the Effect of COVID-19 Pandemic–Related Lifestyle on Myopia (n = 7)

	Lifestyle Factors				Ocular Outcomes (Cycloplegic Refraction Data for SE Outcomes)				
References	**Type of Lifestyle Factor***	**During COVID† (h/d)**	**Pre-COVID† (h/d)**	***P* Value§**	**Type of Ocular Outcome**	**During COVID†**	**Pre-COVID†**	***P* Value‖**	**Effect Estimate‡ (During COVID Minus Pre-COVID) (95% CI)**
Studies assessing changes in myopia outcomes in periods during COVID vs pre-COVID									
Zhang et al[52]	Time outdoors	0.4 ± 0.9	1.2 ± 0.9	NA	ΔSE/y	−0.80 D¶	−0.41 D¶	NA	−0.35 D (−0.42, −0.29)
	Near-work	8.1 ± 4.5	4.0 ± 2.6	NA	ΔAL/y	0.45 mm¶	0.28 mm¶	NA	0.16 mm (0.12, 0.20)
	Screen time	6.9 ± 4.4	2.8 ± 1.1	NA	Annual myopia incidence	29.7%¶	11.6%¶	0.03#	18.1% (14.2, 22.0)
Hu et al[53]		NA			ΔSE/y	−0.67 ± 0.56 D	−0.31 ± 0.46 D	< 0.001**	−0.36 D (−0.41, −0.32)
					ΔAL/y	0.31 ± 0.24 mm	0.22 ± 0.21 mm	< 0.001**	0.08 mm (0.06, 0.10)
					Annual myopia incidence	15.3%	7.5%	< 0.001#	7.9% (5.1, 10.6)
Ma et al[54]	Time outdoors	1.0 ± 1.0	1.8 ± 1.4	< 0.001	ΔSE/7 mo	−0.83 ± 0.56 D	−0.33 ± 0.46 D	< 0.001††	−0.50 D (−0.66, −0.34)
	Near-work	4.3 ± 1.0	3.0 ± 1.1	< 0.001	ΔAL/7 mo	0.22 ± 0.22 mm	0.21 ± 0.21 mm	0.97††	0.01 mm (−0.06, 0.08)
	Screen time	1.8 ± 0.7	NA	< 0.001	Myopia prevalence	84.4%	32.5%	NA	51.9% (41.4, 62.4)
Ma et al[55]	Time outdoors	0.9 ± 1.0	1.8 ± 1.5	< 0.001	ΔSE/7 mo	−0.93 ± 0.65 D	−0.33 ± 0.47 D	< 0.001	−0.60 D (−0.71, −0.49)
	Near-work	1.8 ± 1.1	1.5 ± 1.0	< 0.001	ΔAL/7 mo	0.24 ± 0.19 mm	0.23 ± 0.18 mm	0.37	0.01 mm (−0.03, 0.05)
	Screen time	2.4 ± 2.2	1.4 ± 1.8	< 0.001	Myopia incidence (7 mo)	65.1%	27.1%	NA	38.0% (25.1, 50.9)
Ma et al[56]	Time outdoors	0.5 ± 0.2	1.1 ± 0.4	< 0.001	ΔSE/6 mo	−0.98 ± 0.52 D	−0.39 ± 0.58 D	< 0.001	−0.59 D (−0.70, −0.48)
	Near-work	1.0 ± 0.4	2.1 ± 0.6	< 0.001					
	Screen time	5.2 ± 0.8	0.7 ± 0.3	< 0.001					
Studies assessing myopia outcomes at time points during COVID vs pre-COVID									
Yao et al[42]	NA				SE	0.59 ± 1.08 D	1.07 ± 0.92 D	< 0.05	−0.48 D (−0.55, −0.41)
Aslan et al[43]	NA				SE	−2.71 ± 1.21 D	−1.99 ± 1.04 D	NA	−0.72 D (−1.01, −0.43)

*All studies used questionnaires to collect self or parental reported lifestyle factors. Time outdoors may include outdoor activities for sports or leisure. Near-work activities may include reading and writing, crafts, homework (using paper and pen) for school or leisure. Screen time may include the use of handheld electronic devices (smartphones, tablets, or other gaming devices), computers, or watching television for school or leisure.

†Mean ± SD was presented for continuous lifestyle factors or myopia outcomes (or percentages for binary myopia outcomes) where available. For ΔAL outcome in the study by Ma et al[54], the mean and SD were transformed from reported median and interquartile range by using the formulae by Hozo et al.[44]

‡For continuous outcomes, the effect estimate was the difference in means (or difference in means of changes) between time points (or periods) during COVID and pre-COVID. For binary outcomes, the effect estimate was the difference in proportions between during COVID and pre-COVID. Effect estimates were reported in one study: Hu et al[53]; otherwise, the 95% CI of each effect estimate was computed using the formulae detailed in the study by Borenstein and colleagues[45,46] for paired groups (or independent groups[52]) from during-COVID and pre-COVID (for binary or continuous variables).

§*P* value from paired *t* test; except for Ma et al,[54] where *P* value was from the Wilcoxon signed-rank test.

‖*P* value from paired *t* test, unless otherwise specified.

¶Annualized myopia outcomes in each period were reported (SDs or standard errors not available). Using available myopic shift information that was not annualized, the computed annualized myopic shift in the period pre-COVID of −0.41 ± 0.43 D was comparable to the reported value of −0.41 D, and the computed annualized myopic shift in the period during COVID of −0.76 ± 0.78 D was within an absolute discrepancy of 5% from the reported value of −0.80 D. Similarly, the computed annualized axial elongation in the period pre-COVID of −0.28 ± 0.16 mm was comparable to the reported value of −0.28 mm, and the computed annualized axial elongation in the period during COVID of −0.44 ± 0.53 mm was within an absolute discrepancy of 2% from the reported value of −0.45 mm.

#In the study by Zhang et al,[52] *P* value from log binomial model for assessing whether myopia incidence between periods during COVID and pre-COVID were different (after adjusting for age, sex, parental myopia status, duration of follow-up period, time outdoors and near-work). In the study by Hu et al,[53] *P* value was from the χ^2 test.

***P* value from Student 2-sample *t* test.

††*P* value from Wilcoxon signed-rank test.

AL indicates axial length; CI, confidence interval; COVID-19, coronavirus disease 2019; D, diopters; h, hour(s); mo, months; NA, not available; SE, spherical equivalent.

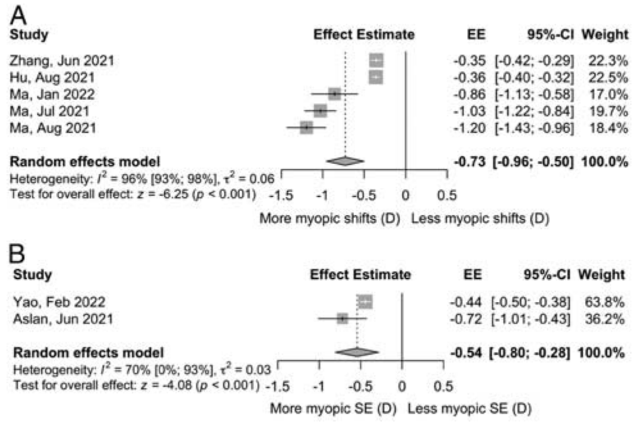

FIGURE 2. Forest plots of all 7 studies on the difference in annualized myopic shifts (n = 5) (A) or annualized difference in SE (n = 2) (B) between during COVID and pre-COVID periods. A, Forest plot included 5 prospective cohort studies. Pooled EE refer to difference in annualized myopic shifts (ie, period during COVID minus pre-COVID) using the generic inverse variance approach with random effects. B, Forest plot included 2 studies (1 prospective cohort and 1 repeated cross-sectional study). Pooled EEs refer to the annualized difference in SE (ie, time point during COVID minus pre-COVID) using the generic inverse variance approach with random effects. CI indicates confidence interval; COVID-19, coronavirus disease 2019; EE, effect estimate; SE, spherical equivalent.

periods suggested sample sizes and study population as possible factors. Two studies with larger sample sizes ($\geq$1000 participants) had much lower heterogeneity (pooled effect estimates: −0.36 D/y; 95% CI: −0.39, −0.32; $I^2 = 0\%$; $\tau^2 = 0$), compared with that of the remaining 3 studies with smaller sample sizes (pooled effect estimates: −1.04 D/y; 95% CI: −1.21, −0.87; $I^2 = 41\%$; $\tau^2 = 0.01$) ($P < 0.001$ for subgroup differences). Population-based or school-based samples (−0.42 D/y; 95% CI: −0.54, −0.31; $I^2 = 83.7\%$; $\tau^2 = 0.01$) produced smaller pooled effect estimates compared with that of hospital-based studies (−1.10 D/y; 95% CI: −1.26, −0.93; $I^2 = 17.3\%$; $\tau^2 = 0.002$) ($P < 0.001$ for subgroup differences).

In the sensitivity analyses, pooled effect estimates (of the difference in means of changes) similarly suggested significantly more myopic shift in the period during COVID (compared with pre-COVID), where studies with paired samples were assumed to have nonzero correlation (r), that is, r is 0.25 (−0.74 D/y; 95% CI: −0.99, −0.49; $P < 0.001$; $I^2 = 96\%$; $\tau^2 = 0.07$), r is 0.50 (−0.75 D/y; 95% CI: −1.02, −0.47; $P < 0.001$; $I^2 = 98\%$; $\tau^2 = 0.09$), or r is 0.75 (−0.76 D/y; 95% CI: −1.07, −0.44; $P < 0.001$; $I^2 = 99\%$; $\tau^2 = 0.13$); or when nonannualized effect estimates were pooled (−0.47 D; 95% CI: −0.57, −0.37; $P < 0.001$; $I^2 = 87\%$; 95% CI: 73, 94; $\tau^2 = 0.01$). The Egger test suggested the presence of funnel plot asymmetry ($P = 0.023$) in the main analyses, although it was of borderline significance ($P = 0.046$) when r was 0.75 and was no longer significant ($P = 0.08$) using nonannualized effect estimates.

In addition, the overall conclusion of significantly more myopic SE at time points during COVID (compared with pre-COVID) remained unchanged in sensitivity analyses where paired samples was assumed to have nonzero correlation (r), that is, r is 0.25 (−0.55 D/y: 95% CI: −0.82, −0.29; $P < 0.001$; $I^2 = 77\%$; 95% CI: 1, 95; $\tau^2 = 0.03$), r is 0.50 (−0.56 D/y; 95% CI: −0.83, −0.29; $P < 0.001$; $I^2 = 85\%$; 95% CI: 38, 96; $\tau^2 = 0.03$), or r is 0.75 (−0.57 D/y; 95% CI: −0.84, −0.30; $P < 0.001$; $I^2 = 92\%$; 95% CI: 73, 98; $\tau^2 = 0.04$); or where nonannualized effect estimates were pooled (−0.53 D; 95% CI: −0.73, −0.34; $P < 0.001$; $I^2 = 40\%$; $\tau^2 = 0.01$).

DISCUSSION

Overall, in all 7 studies included in this review, there was evidence that the COVID-19 pandemic–related lifestyle had adversely impacted SE in a more myopic direction.[42,43,52–56] Of the 7 selected studies, 5 studies reported significantly more myopic shifts[52–56] in the period during COVID, and 2 remaining studies reported significantly more myopic SE[42,43] at the time point during COVID, compared with pre-COVID, respectively.

In all 5 studies that reported significantly more myopic shifts during COVID compared with pre-COVID,[52–56] the annualized effect estimates (of the difference in means of changes) ranged from around −1.20 to −0.35 D/y. Across these 5 studies, annualized myopic shifts in the period during COVID alone ranged from around −1.96 to −0.67 D/y.[52–56] It was not possible to differentiate if larger effect estimates were attributed to differences in age, SE, study population type, or other factors. However, given the comparable mean ages (and the overlapping age ranges) across studies, there may be a limited influence of age on outcomes. Studies with more myopic SE at baseline had faster myopic shifts (or larger differences in annualized means of myopic shifts) during COVID than pre-COVID (effect estimates: −1.20 to −0.86 D/y where mean SE $\leq$ −0.50 D; −0.36 to −0.35 D/y where mean SE > −0.50 D). This agreed with previous reports of faster SE progression in children with more myopic baseline SE.[65,66] In contrast, studies with less myopic baseline SE (SE > −0.50 D) had significant and faster ΔAL during COVID (difference in means of changes of around 0.08 to 0.16 mm/y), compared with nonsignificant ΔAL ($P > 0.05$ for all) of much smaller effect estimates (around 0.01 mm/y) in studies with more myopic baseline SE (SE $\leq$ −0.50 D). Further subgroup analyses suggested that the pooled estimates (of the difference in means of changes in myopic shifts) were more pronounced in hospital-based studies (−1.10 D/y; 95% CI: −1.26, −0.93) than in population-based or school-based samples (−0.42 D/y; 95% CI: −0.54, −0.31) ($P < 0.001$ for subgroup differences). Other population characteristics, study methodologies, or factors including regional variations in education, economic developments, and cultural or other lifestyle factors may also have contributed to the observed heterogeneity. Regardless, all studies reported faster annualized myopic shifts (or more myopic SE) during COVID, compared with pre-COVID.

Corroborating with these findings, significantly higher myopia incidence (of around 2.0- to 2.6-fold increase) was reported in the period during COVID (compared with pre-COVID).[52,53,55] Together, the effects of pandemic-related lifestyle on significantly faster annualized myopic shifts (pooled difference in means of changes of −0.73 D/y), more myopic SE (pooled difference in means of −0.54 D/y), and increased myopia incidence during COVID (compared with pre-COVID) are clinically relevant. The pandemic-related lifestyle may place children at higher risks of myopia onset at an earlier age, more severe myopic SE, and potentially faster subsequent SE progression.[67] Early age of myopia onset may predict high myopia[68] in later childhood, consequently increasing the risks for myopic macular degeneration[69] in adulthood. Detailed investigations are also needed to verify if these myopic changes are reversible or permanent, as per additional diopter of SE in a myopic direction has been associated with a 67% increased risk of myopic maculopathy, the most common sight-threatening complication of myopia.[70] Ensuring adequate access to eye care services during the pandemic is thus, critical.

Although there was evidence for significantly more myopic shifts and higher myopia incidence in the period during COVID, evidence for ΔAL was mixed. Although 2 larger studies (n = 1793 and n = 2114) reported significantly faster ΔAL (ranging approximately from 0.08 to 0.16 mm) during COVID (vs pre-COVID), 2 other smaller studies (n = 77 and n = 208) reported null findings. In the 2 larger studies, the inclusion of participants from more metropolitan cities (hence possibly heightened exposures to environmental risk factors) and a longer duration of follow-up periods may partly explain differences in findings from the 2 other smaller studies, in addition to other variations in population characteristics or study methodologies. Further research is needed to examine the long-term effects of the pandemic on ΔAL.

In parallel with the changes in myopia outcomes, there were reports of significantly decreased time outdoors and significantly increased screen time during COVID. Notably, time outdoors during COVID were reported to be ≤1 h/d. Other studies have similarly reported significantly decreased time outdoors[30] or increased screen time[31,32] during COVID. There is evidence that increased time outdoors may be protective against incident myopia or myopic shifts.[13,14] Light intensity (regulating dopamine release),[71–73] chromaticity,[74,75] and more peripheral myopic defocus have been postulated to confer this protection.[9] The changes in myopia outcomes during COVID may partly be attributed to the lower time outdoors, which were below levels demonstrated to protect against myopia onset and myopic shifts.[76–79] Although the studies in this review have assessed key environmental risk factors for myopia, possible influences from other unmeasured lifestyle changes could not be ruled out. Future investigations delineating the effects of COVID-19–related lifestyle factors (independently or in combination using objective measures) may reveal insights into effective myopia prevention measures.

The potential negative consequences of the COVID-19 pandemic–related lifestyle on myopia need to be carefully considered in the design of future restriction measures, with minimal disruption to outdoor activities. Schools play an important role in conducting organized outdoor activities, not limited to outdoor education initiatives, or physically conducting lessons outdoors. In China, efforts have been made to structure and enforce learning breaks in a manner that would better allow children to get outdoors between classes, in addition to the implementation of daily after-school and outdoor holiday programs across public schools.[80] As myopia prevention efforts are often closely integrated within school systems in several Asian countries,[81] there needs to be a balance between restriction measures and the ability to perform outdoor activities while safe distancing. In regions with more widespread and extended restriction measures, allowing for outdoor activities if performed alone or with family members may be considered. Constant public health messaging to encourage time outdoors in open spaces (eg, having meals outdoors or increasing park use) during the pandemic should be aimed at parents, who play critical roles in the planning of outdoor activities and serve as role models for children.[30]

This review has limitations. First, the conclusions from this review should be considered in light of limitations from individual studies, including possible selection bias of study participants and recall bias in the assessment of changes in lifestyle factors. Second, the heterogeneity of included studies and the noncomparability of durations of study periods (pre-COVID and during COVID) may limit direct comparisons across studies, warranting cautious interpretation of pooled estimates. Hospital-based studies may be prone to selection bias and may give rise to spurious effect estimates. Third, the computation of annualized myopic shifts may have introduced bias. However, there was a low discrepancy between the reported and computed annualized changes in each period (within an absolute discrepancy of 5%), suggesting that the transformation may have been reasonable. Third, direct associations between changes in specific lifestyle factors and changes in each myopia outcome could not be established as most of the included studies have presented myopia outcomes in parallel with COVID-19 pandemic–related lifestyle factors. Last, most studies in this review were conducted in Asian populations. However, these findings may be generalizable to other populations. Evidence on the links between higher levels of time outdoors with lower incident myopia[13,14,82,83] or higher levels of near-work[82,84] with more myopia has been documented in both Asian and Caucasian populations. In Chinese elementary school children, an additional 40 to 80 min/d of time outdoors reduced the risks of myopia onset by around 23% to 50%.[13,14] Similarly, in American children aged 8 to 9 y, increasing time outdoors from 0 to 5 hours to over 14 hours per week (or approximately an additional 80–120 min/d) may reduce the risk of myopia onset by approximately over one third.[79,85] Although differences in study methodologies may limit direct comparisons, there is some evidence that changes to key myopia risk factors may exert comparable effects across populations. It is thus conceivable that the effects of the pandemic-related lifestyle on myopia might not only be limited to Asian populations, particularly given the protracted nature of the pandemic and its inevitable impact on lifestyle changes.

This systematic review of the best studies provided evidence of significantly more myopic shifts in SE during COVID (compared with pre-COVID) in participants aged 6 to 17 y. In parallel with more myopic shifts, there was decreased time outdoors and increased screen time. As the COVID-19 pandemic–related lifestyle (including indoor-centric activities and mass shifts toward digitalization of education) may likely persist in parts of the world, the extent to which it may reverse the recent progress in myopia prevention efforts or exacerbate the myopia epidemic in the long term warrants attention.

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