Association between digital smart device use and myopia: a systematic review and meta-analysis

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Summary

Background Excessive use of digital smart devices, including smartphones and tablet computers, could be a risk factor for myopia. We aimed to review the literature on the association between digital smart device use and myopia.

Methods In this systematic review and meta-analysis we searched MEDLINE and Embase, and manually searched reference lists for primary research articles investigating smart device (ie, smartphones and tablets) exposure and myopia in children and young adults (aged 3 months to 33 years) from database inception to June 2 (MEDLINE) and June 3 (Embase), 2020. We included studies that investigated myopia-related outcomes of prevalent or incident myopia, myopia progression rate, axial length, or spherical equivalent. Studies were excluded if they were reviews or case reports, did not investigate myopia-related outcomes, or did not investigate risk factors for myopia. Bias was assessed with the Joanna Briggs Institute Critical Appraisal Checklists for analytical cross-sectional and cohort studies. We categorised studies as follows: category one studies investigated smart device use independently; category two studies investigated smart device use in combination with computer use; and category three studies investigated smart device use with other near-vision tasks that were not screen-based. We extracted unadjusted and adjusted odds ratios (ORs), β coefficients, prevalence ratios, Spearman's correlation coefficients, and p values for associations between screen time and incident or prevalent myopia. We did a meta-analysis of the association between screen time and prevalent or incident myopia for category one articles alone and for category one and two articles combined. Random-effects models were used when study heterogeneity was high (I^2>50%) and fixed-effects models were used when heterogeneity was low (I^2≤50%).

Findings 3325 articles were identified, of which 33 were included in the systematic review and 11 were included in the meta-analysis. Four (40%) of ten category one articles, eight (80%) of ten category two articles, and all 13 category three articles used objective measures to identify myopia (refraction), whereas the remaining studies used questionnaires to identify myopia. Screen exposure was measured by use of questionnaires in all studies, with one also measuring device-recorded network data consumption. Associations between screen exposure and prevalent or incident myopia, an increased myopic spherical equivalent, and longer axial length were reported in five (50%) category one and six (60%) category two articles. Smart device screen time alone (OR 1·26 [95% CI 1·00–1·60]; I^2=77%) or in combination with computer use (1·77 [1·28–2·45]; I^2=87%) was significantly associated with myopia. The most common sources of risk of bias were that all 33 studies did not include reliable measures of screen time, seven (21%) did not objectively measure myopia, and nine (27%) did not identify or adjust for confounders in the analysis. The high heterogeneity between studies included in the meta-analysis resulted from variability in sample size (range 155–19 934 participants), the mean age of participants (3–16 years), the standard error of the estimated odds of prevalent or incident myopia (0·02–2·21), and the use of continuous (six [55%] of 11) versus categorical (five [46%]) screen time variables

Interpretation Smart device exposure might be associated with an increased risk of myopia. Research with objective measures of screen time and myopia-related outcomes that investigates smart device exposure as an independent risk factor is required.

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Introduction

The prevalence of myopia is increasing worldwide, with half of the global population expected to have myopia by 2050.[1] This trend has been accompanied by a reduction in the age of onset,[2] an acceleration in the rate of progression, and an increase in the severity of myopia at stabilisation,[3,4] all of which portend a surge in the global burden of high myopia and its complications, such as irreversible blindness, in the coming decades.[1,4,5]

The myopia epidemic is likely to be driven by exposure to environmental risk factors present in ever more urbanised and developed societies, with two major risk factors of particular concern: insufficient time spent outdoors and more time engaged in so-called near-vision

Research in context

Evidence before this study

We searched MEDLINE on May 19, 2020 using natural language search terms, including "smartphone", "tablet computer", "screen time", "digital screens", "mobile phone", "cell phone", "myopia", and "refractive error", as well as corresponding indexing medical subject heading terms, including "Cell Phone", "Screen Time", "Smartphone", "Social Media", "Video Games", "Computers", "Handheld", "User-Computer Interface", "Data Display", "Myopia", and "Refractive Errors". We searched for primary research and reviews reporting associations between exposure to digital smart device screens (smartphones and tablet computers) and myopia, published in any language between database inception and May 19, 2020. We identified cross-sectional and longitudinal studies, with some investigating smart device use as an independent risk factor and others investigating smart device use together with other near-vision tasks, including computer use and reading. The findings were inconsistent, with some studies reporting strong associations between screen time and myopia (odds ratio 8·33 [95% CI 3·54–19·58] for 2–4 h per week *vs* 0–2 h per week) and others finding no associations or even protective effects of screen time. One identified meta-analysis concluded that screen time was not a risk factor for myopia. However, smartphones and tablets were not studied independently of other digital screens, a small number of studies (n=13) were included in the systematic review (five studies were included in the meta-analysis, of which only one interrogated smart devices independently of other risk factors), and the reasoning behind their statistical methods was not clear. Therefore, we did a systematic review and meta-analysis to address these gaps in the literature, to critically appraise the available studies, and to investigate whether there is a potential association between smart device exposure and myopia.

Added value of this study

We did a comprehensive systematic review and meta-analysis of the literature on the association between smart device screen exposure and myopia. Through our appraisal of 33 available articles, we identified limitations in study design, including that most studies did not investigate smartphone and tablet use independently of other near-vision tasks; many studies did not use objective clinical measures to identify myopia; and all studies used self-reported measures of screen time. Half of studies that investigated smart device use independently reported significant associations with myopia or axial elongation, whereas 60% of articles that investigated smart device use combined with computer use reported significant associations. By constructing different meta-analysis models, we analysed the associations between myopia and use of smartphones or tablets, or both, alone and in combination with computer screen time in order to distinguish associations for smart devices from other forms of near-vision tasks. We found that smartphone and tablet screen time alone and in combination with computer screen time were significantly associated with myopia, although no associations were observed when only prospective studies were pooled. High heterogeneity and an absence of objective and standardised measurement of myopia and screen time among studies, as revealed by our review, limited strong inference based on the meta-analysis models, and provides the impetus for future studies to measure smart device screen time independently and to measure myopia objectively.

Implications of all the available evidence

Further research is required, including high quality prospective studies or randomised controlled trials that objectively measure both screen time and refraction, to conclusively establish whether there is an association between smart device exposure and myopia. Nonetheless, this systematic review and meta-analysis provides some evidence to suggest that exposure to digital smart devices could be a modifiable risk factor for myopia. The increasing uptake and lengthy exposure to smart devices among children worldwide could lead to an increase in the global burden of myopia and its complications, such as irreversible vision loss. Public health interventions that promote responsible use of digital screens could support myopia control efforts.

work activities during childhood.[6–8] The ubiquitous adoption of digital smart devices (ie, smartphones and tablet computers) in the past decade constitutes a new form of near-vision work, and children use these devices for long uninterrupted periods (approximately 8 h per day), and at viewing distances closer than for conventional books.[9–11] There is emerging evidence describing the varied adverse consequences of excessive smart device use,[12–16] and, although the increased prevalence of myopia precedes the advent of smart devices,[1] it has been suggested that these devices could be exacerbating the myopia epidemic.[17] However, this association has not been extensively investigated. Population-based studies have started to reveal a link between screen time and myopia, with a higher prevalence of myopia,[18,19] increased myopic spherical equivalent,[20] and longer axial length[21] being associated with more screen time, whereas other studies have found no link,[22,23] necessitating further investigation.

A recent systematic review published in 2020,[24] attempted to clarify the association between digital screen time and prevalent or incident myopia, and found no association based on a meta-analysis of five studies. Only one included study investigated handheld devices independently of other types of digital screens, whereas the remaining studies either included a combination of handheld devices and computers, or computers alone without smart devices.

To address these important knowledge gaps, we did a systematic review and meta-analysis to investigate the association between myopia and digital screen use, with a focus on smart devices. We attempted to separate the use of smart devices from computers and other near-vision work that does not involve digital screens.

Methods

Search strategy and selection criteria

In this systematic review and meta-analysis, we searched MEDLINE and Embase, and manually searched reference lists on June 2 and June 3, 2020, for peer-reviewed original primary research articles, including observational or interventional studies, describing the association between smart device exposure and myopia. The systematic review was done in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[25] For the search of MEDLINE we used the search terms (Cell Phone OR Screen Time OR Smartphone OR Social Media OR Video Games OR Computers, Handheld OR User-Computer Interface OR Data Display OR Risk Factors OR Health Risk Behaviors OR Risk) AND (Myopia OR Refractive Errors). Search terms were chosen to be sufficiently inclusive so that publications that included smart devices as one of a multitude of risk factors for myopia were identified (see the appendix [p 1] for a full list of the search terms used). We searched for articles published from database inception to the dates of the search, with no language restrictions.

Two reviewers (JF and ATS) screened all titles and abstracts. Articles that investigated risk factors for myopia, even if smart devices were not mentioned, were not excluded at this stage because smart device use might have been reported in the main text. Articles were excluded if they were reviews or case reports, did not investigate myopia-related outcomes (ie, the prevalence or incidence of myopia, myopia progression rate, age of myopia onset, spherical equivalent, and axial length), or did not investigate risk factors for myopia.

Both reviewers (JF and ATS) read the full texts of all remaining articles. Articles were excluded if risk factor analysis did not include mobile phones or tablets, either separately or combined with other forms of near-vision tasks, or if myopia-related outcomes were not measured. Conflicts over inclusion were adjudicated by a third reviewer, MD. All excluded articles are listed in the appendix (pp 2–14). All remaining articles were appraised by use of the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-Sectional Studies and the JBI Critical Appraisal Checklist for Cohort Studies to assess their methodological quality and risk of bias.[26] Studies affected by bias were not excluded from the systematic review, as their inclusion and a discussion of their limitations was necessary for a full appraisal of the literature. Studies with unclear statistical analysis or reporting of results were excluded. The remaining studies were included, and their reference lists were searched for additional literature.

All articles included in the meta-analysis were derived from those included in the systematic review. Studies were included in the meta-analysis if they reported adjusted odds ratios (ORs) for the association between exposure to smart devices and prevalent or incident myopia, or other adjusted measures of association that could be converted to ORs, such as β coefficients, associated with digital smart device screen time, alone or in combination with computer screen time.

Included articles were divided into three categories: category one studies included those in which smart devices (smartphones or tablets, or both) were investigated as an independent risk factor; category two studies included those in which smart devices were investigated but not independently of computer screen exposure; and category three studies were those in which smart device use was investigated, but not independently of other forms of near-vision activities, such as watching television, reading non-digital books, and writing.

Data analysis

Data were extracted from studies by JF, ATS, and AP. Variables that were extracted were study design, sampling methodology, sample size, participants' age and country (and city, when available) of residence, response rates, myopia definition and measurement (including objective *vs* subjective methods), screen exposure measures (including type of screen exposure, inclusion of other near-vision task exposures, screen time, and duration of measurement of exposure), myopia-related outcomes (including prevalence, incidence, progression rate, axial length, and spherical equivalent), statistical associations between smart device exposure and myopia-related outcomes (including ORs, prevalence ratios, β coefficients, 95% CIs, and p values), and variables for which associations between smart device screen exposure and myopia-related outcomes were adjusted in multivariable analysis.

See Online for appendix

The characteristics of all included studies were tabulated and described in the systematic review. The meta-analysis was done by pooling adjusted ORs for associations between screen time and incident or prevalent myopia. Univariate ORs were not included. Models were developed to explore associations for category one studies alone and for category one and two studies combined. No models were generated with category three studies.

Random-effects models were used when study heterogeneity was high (I^2>50%) and fixed-effects models were used when heterogeneity was low (I^2≤50%). ORs were weighted according to the inverse of study variance, with random-effects models accounting for both intra-study and inter-study variance, thus increasing the distribution of weights more uniformly than fixed-effects models. Transformations done to facilitate inclusion of

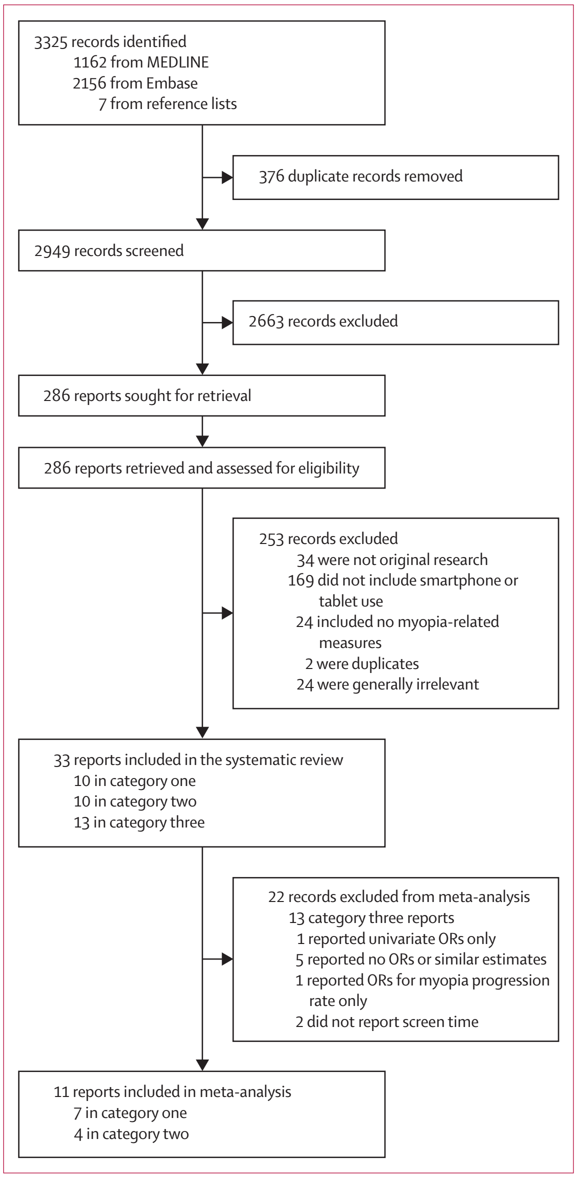

Figure 1: **Study selection**
OR=odds ratio.

results in the meta-analysis included: conversion of β coefficients to ORs;[27] standardisation of an OR associated with screen time from min per day to h per day,[28] according to the formula $OR_{h\ per\ day}=\exp(\ln[OR_{min\ per\ day}]\times60)$, which was done with the aim of increasing homogeneity but should be considered cautiously, as it assumes an additive effect of screen time; and derivation of a reciprocal OR[18] to establish the lowest category of screen time as the reference group for compatibility with other studies. When ORs were reported for multiple groups of a categorical variable,[18,19,27,29,30] all ORs were included, as described by Yu and colleagues.[31] For studies that reported ORs for multiple exposure variables among non-mutually exclusive samples, such as weekend and weekday use[19] or duration of tablet and smartphone use,[23,32] we selected ORs for variables to which the larger sample was exposed[23,32] and for which more days of data were collected (ie, weekdays *vs* weekends).[19]

Statistical analyses were done using R, version 4.0.3.

Role of the funding source

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Results

The database search yielded 3318 articles, with a further seven articles included from reference lists (figure 1). A total of 286 full-text articles were assessed for eligibility. Of these, 35 were appraised with the JBI checklists, with two being excluded due to concerns regarding the statistical analysis and reporting[33,34] (appendix p3), resulting in 33 articles[18–23,27–30,32,35–56] being included in the systematic review. The characteristics of all included studies are shown in table 1 and in the appendix (pp 28–29). Ten (30%) studies[18,20,23,27,28,32,35–38] met the criteria for inclusion in category one, ten (30%) studies[19,21,22,29,30,39–43] for inclusion in category two (table 1), and 13 (39%) studies[44–56] for inclusion in category three (appendix pp 28–29). Seven (70%) category one studies[18,20,23,27,28,32,35] and four (40%) category two studies[19,22,29,30] were included in the meta-analysis.

Risk of bias assessment with the JBI Critical Appraisal Checklists revealed the following sources of bias: the absence of valid or reliable measurement of exposure in all 33 studies; the absence of objective standard criteria for measurement of the condition in seven (21%) studies;[22,28,32,36–38,42] no assessment of confounders in nine (27%) studies;[21,39,41,42,45,48,52,55,56] insufficient strategies for dealing with confounders in nine (27%) studies;[21,28,39,40,42,45,48,52,55] incomplete follow-up in three (9%) studies;[19,51,54] the absence of strategies to address incomplete follow-up in four (12%) studies;[19,35,51,54] and unclear reporting of whether participants were free from myopia at baseline in two (6%) studies.[32,51] Specific comments about the sources of bias for each study are provided in the appendix (pp 15–27).

Most category one studies (seven [70%] of ten) and category two studies (six [60%] of ten) investigated Asian populations.[20,21,23,27,29,30,32,35–37,40,41,43] Even though some European studies[18,19,22,28,38,39,42] were included, no eligible studies from other world regions were identified. Similarly, category three studies were mostly done in east Asia (nine [69%] of 13)[45–51,53,55] or Europe (three [23%]),[44,52,54] with one done in the Middle East.[56] Eight (80%) category one studies,[18,20,27,28,32,36–38] seven (70%) category two studies,[21,22,29,30,39,41,42] and 11 (85%) category three studies[44–50,52,53,55,56] were cross-sectional, and the remaining two category one studies,[23,35] three category two studies,[19,40,43] and two category three studies[51,54] were prospective.

Population-based surveys, such as the North India Myopia (NIM) study, selected participants by cluster sampling of classes, or schools or districts, or both.[18,20,27,29,37,47] Stratification by school and age was common,[20,23,32,36,47,48,53] whereas stratification by other variables such as urban or rural location, socioeconomic status,[18] or type of school[32] was rare. Although some studies adjusted for confounders in statistical analyses,[18,19,23,32,35,37,38] variability in selected covariates could have caused bias. Some studies used pseudo-random

	Participants; age; country	Response rate	Myopia definition (measure)	Screen exposure (period of exposure)*	Myopia prevalence or incidence by smart device exposure, or screen time by myopia status	Association between exposure and myopia
Category one studies: use of smartphones or tablet computers, or both, analysed independently of other near vision activities						
Cross-sectional studies						
Guan et al (2019)[27]	19 934 primary school children; mean age 10·6 years (SD 1·15); China	100%	Spherical equivalent ≤–0·5 dioptres in at least one eye (visual acuity and auto-refraction)	Smartphone screen time (period not reported)	0 min per day 17·5%; 1–30 min per day 19·4%; 31–60 min per day 18·0%; and >60 min per day 20·0%	Multivariable analysis of smartphone use and myopia: 0 min per day β coefficient 1 (ref); 1–30 min per day 0·03 (95% CI –0·07 to 0·12, p=0·59); 31–60 min per day –0·02 (–0·22 to 0·19, p=0·89); >60 min per day 0·16 (–0·07 to 0·39, p=0·17)
Harrington et al (2019)[18]	1626 school children; age 6–7 years and 12–13 years; Ireland	98·5%	Spherical equivalent ≤–0·5 dioptres in either eye (auto-refraction)	Smartphone screen time (period not reported)	<1 h per day 8·3%; 1–3 h per day 11·7%; and >3 h per day 20·3%	Multivariable analysis of smartphone screen time and myopia: <1 h per day OR 0·3 (95% CI 0·2–0·5, p<0·001); 1–3 h per day 0·5 (0·3–0·8, p=0·001); and >3 h per day 1 (ref)
Huang et al (2019)[36]	968 first year university students; mean age 19·6 years (SD 0·9); China	96·1%	Spectacles or contact lenses for distant vision (questionnaire)	Smartphone screen time (period not reported)	0 h per day 89·7%; ≤1 h per day 87·1%; 1·01–2 h per day 89·7%; 2·01–3 h per day 86·3%; and >3 h per day 84·6%	Univariate analysis of smartphone screen time and myopia: 0 h per day OR 1 (ref); ≤1 h per day 0·78 (95% CI 0·36–1·69, p=0·52); 1·01–2 h per day 1·01 (0·47–2·18, p=0·99); 2·01–3 h per day 0·72 (0·36–1·46, p=0·36); >3 h per day 0·63 (0·33–1·20, p=0·16)
Liu et al (2019)[20]	566 primary and secondary school children; mean age 9·5 years (SD 2·1); China	88·7%	Spherical equivalent ≤–0·5 dioptres in right eye (auto-refraction)	Smartphone and tablet screen time (period not reported)	Smartphones: myopia 0·47 (SD 0·49) h per day *vs* no myopia 0·39 (0·47) h per day (p=0·038; adjusted p=0·93); tablets: myopia 0·34 (0·46) h per day *vs* no myopia 0·26 (0·47) h per day (p=0·040; adjusted p=0·11)	Smartphone screen time and myopia multivariable OR 0·90 (95% CI 0·57 to 1·43, p=0·66); tablet screen time and myopia multivariable OR 1·40 (0·86 to 2·28, p=0·18); smartphone screen time and axial length β coefficient 0·10 (95% CI 0·07 to 0·39, p=0·006); tablet screen time and axial length β coefficient –0·03 (0·23 to 0·10, p=0·45); smartphone screen time and spherical equivalent β coefficient –0·07 (–0·55 to –0·01, p=0·042); and tablet screen time and spherical equivalent β coefficient –0·05 (–0·47 to 0·08, p=0·17)
McCrann et al (2020)[28]	402 students; mean age 16·8 years (SD 4·4); Ireland	96·1%	Concave spectacle lenses (questionnaire)	Smartphone screen time (period not reported)	Myopia 288 (SD 174) min per day *vs* no myopia 258 (163) min per day (p=0·090)	Smartphone screen time and myopia multivariable OR 1·03 (95% CI 1·00–1·05)
Schuster et al (2017)[38]	12 884 children and adolescents; age 3–17 years; Germany	66·6%	Self-reported (questionnaire)	Mobile phone screen time (period not reported)	Not reported	Multivariable analysis of mobile phone screen time and myopia in participants aged 11–17 years: <0·5 h per day 1–2 h per day 0·99 (95% CI 0·78–1·25); 3–4 h per day 0·83 (0·52–1·31); and >4 h per day 1·34 (0·99–1·82); p=0·14
Toh et al (2019)[32]	1884 adolescents; age 10–18 years; Singapore	74·1%	Difficulties in seeing far (questionnaire)	Mobile touch-screen device time (number of min per day in past year)	Not reported	Smartphone screen time and myopia multivariable OR 0·97 (95% CI 0·94–0·99, p<0·05); tablet screen time and myopia multivariable OR 0·99 (0·94–1·05)
Yang et al (2020)[37]	26 433 preschool children; age 2–7 years; China	Not reported	Self-reported yes, no, or uncertain (questionnaire)	Initial age of exposure to smartphone or tablet (age of first exposure)	No exposure 1·0%; age 0–1 years 4·5%; age 1–2 years 2·1%; age 2–3 years 1·7%; and age >3 years 1·7%	Multivariable analysis of initial age of exposure: no exposure PR 1 (ref); age 0–1 years 4·41 (95% CI 2·19–8·90, p<0·001); age 1–2 years 2·46 (1·20–5·06, p<0·05); age 2–3 years 2·02 (0·97–4·17); age >3 years 1·78 (0·87–3·65)
Prospective studies						
Chua et al (2015)[35]	925 children; age 3 years; Singapore	74·8%	Spherical equivalent ≤–0·5 dioptres in right eye (auto-refraction)	Handheld device screen time (in h per day; period not reported)	Not reported	Screen time and myopia multivariable OR 1·04 (95% CI 0·67–1·61, p=0·86); screen time and spherical equivalent multivariable β coefficient –0·10 (95% CI –0·20–0·0, p=0·05); and screen time and axial length multivariable β coefficient 0·07 (0·01–0·13, p=0·03)
Toh et al (2020)[23]	1691 adolescents; age 10–19 years; Singapore	89·8%	Difficulties in seeing far (questionnaire)	Any use of smartphones, smartphone screen time, any use of a tablet, or tablet screen time (period not reported)	Not reported	Smartphone use and myopia multivariable OR 0·87 (95% CI 0·42–1·81); smartphone screen time and myopia multivariable OR 0·97 (0·91–1·03); tablet use and myopia multivariable OR 0·74 (0·48–1·15); tablet screen time and myopia multivariable OR 0·98 (0·87–1·10)

(Table 1 continues on next page)

	Participants; age; country	Response rate	Myopia definition (measure)	Screen exposure (period of exposure)*	Myopia prevalence or incidence by smart device exposure, or screen time by myopia status	Association between exposure and myopia
(Continued from previous page)						
Category two studies: use of smartphones or tablet computers, or both, combined with computer screen-time activities						
Cross-sectional studies						
Alvarez-Peregrina et al (2019)[39]	5441 school children; mean age 6·2 years (SD 0·8); Spain	88·4%	Spherical equivalent ≤–0·50 dioptres (auto-refraction)	Smartphone, tablet, and video game screen time expressed as a percentage of time (period not reported)	<25% of time aproximately 24%; 25–50% of time approximately 23%; and >50% of time approximately 53%	More screen time associated with higher prevalence of myopia (p<0·05)
Hagen et al (2018)[22]	439 school children; mean age 16·7 (SD 0·9); Norway	48·9%	Spherical equivalent ≤–0·5 dioptres in right eye (auto-refraction)	Smartphone, tablet, and computer screen time (period not reported)	Not reported	Screen time and myopia multivariable OR 1·01 (95% CI 0·78–1·31, p=0·92)
Hsu et al (2016)[41]	16 486 children; age 8 years; Taiwan	85·1%	Spherical equivalent ≤–0·5 dioptres in more myopic eye (auto-refraction)	Phone, computer, or tablet use (any use in past year)	Yes 36·0%; no 39·1%; and unknown 36·4%	Screen exposure in past year and spherical equivalent multivariable β coefficient 0·82 (0·72–0·92, p<0·001); and screen time and spherical equivalent multivariable β coefficient 0·02 (–0·01–0·13, p=0·11)
McCrann et al (2018)[42]	361 school children from urban and rural schools; age 8–13 years; Ireland	Not reported	Self-reported (questionnaire)	Phone, computer, tablet, and video game screen time (use over 1 week of study participation)	Median 135 min per day (95% CI 78–196) in people with myopia *vs* median 90 min per day (60–158) in those without myopia (ANOVA p=0·04)	Not reported
Saxena et al (2015)[29]	9884 children; mean age 11·6 years (SD 2·2); India	97·7%	Spherical equivalent ≤–0·5 dioptres in either or both eyes (visual acuity and auto-refraction)	Mobile, computer, and video game screen time (period not reported)	0 h per week 1·1%; 1–4 h per week 50·9%; and >4 h per week 48·0%	Multivariable analysis of screen time and myopia: 0 h per week OR 1 (ref); 1–4 h per week 4·50 (95% CI 2·33–8·98); and >4 h per week 8·10 (4·05–16·21)
Singh et al (2019)[30]	1234 school children; mean age 10·5 years (SD 3·0); India	Not reported	Spherical equivalent ≤–0·50 dioptres in either or both eyes (auto-refraction)	Mobile and video game screen time (period not reported)	0–2 h per day: myopia 43% *vs* no myopia 97%; >2–4 h per day: myopia 51% *vs* no myopia 2·4%; and >4 h per day: myopia 7% *vs* no myopia 0%	Multivariable analysis of screen time and myopia: 0–2 h per day OR 1 (ref); >2–4 h per day 8·33 (95% CI 3·54–19·58, p=0·0001)
Terasaki et al (2017)[21]	122 school children; age 8–9 years; Japan	87·4%	Axial length of right eye (optical biometry)	Smartphone and computer screen time (period not reported)	Not applicable	Spearman's correlation analysis between screen time and axial length *r*=0·24, p=0·008
Prospective studies						
Hansen et al (2020)[19]	1443 children; median age 16·6 years (IQR 0·3); Copenhagen, Denmark	Not reported	Spherical equivalent ≤–0·5 dioptres in right eye (subjective and objective refraction)	Smartphone, tablet, or computer screen time (use over past 2 weeks)	Weekdays: <0·5 h per day 0·6%; 0·5–2 h per day 5%; 2–4 h per day 26%; 4–6 h per day 32%; and >6 h per day 37%. Weekends: <0·5 h per day 0%; 0·5–2 h per day 4%; 2–4 h per day 20%; 4–6 h per day 32%; and >6 h per day 44%	Multivariable analysis of screen time and myopia on weekdays: <2 h per day OR 1 (ref); 2–4 h per day 1·89 (95% CI 1·09–3·28, p=0·023); 4–6 h per day 1·68 (0·98–2·89, p=0·06); >6 h per day 1·89 (1·10–3·24, p=0·021). Multivariable analysis of screen time and myopia at weekends: <2 h per day OR 1 (ref); 2–4 h per day 1·73 (95% CI 0·93–3·20, p=0·08); 4–6 h per day 1·62 (0·90–2·94, p=0·11); >6 h per day 1·97 (1·10–3·55 p=0·024)
Hsu et al (2017)[40]	3256 children; age 7·49 years (SD 0·31); Taiwan	77·3%	Spherical equivalent ≤–0·5 dioptres in more myopic eye (auto-refraction)	Phone, computer, or tablet use (use in past year)	Yes 79·91%; no 8·23%; and unknown 11·86%	Multivariable analysis of any screen use in the past year and progression rate: moderate (change in spherical equivalent of >–1·0 to –0·5 dioptres) OR 0·99 (95% CI 0·73–1·33); and fast (change in spherical equivalent of ≤–1·0 dioptres) 1·18 (0·85–1·65)
Tsai et al (2016)[43]	11 590 school children; age 8 years; Taiwan	70·3%	Incident myopia, Spherical equivalent ≤–0·50 dioptres in either eye (auto-refraction)	Phone, computer, and tablet use (use in past year)	87·2% of incident myopia in people who used devices *vs* 87·4% in those who did not (p=0·77)	Not reported

OR=odds ratio. PR=prevalence ratio. *Period of exposure refers to the overall amount of time participants had been exposed to the variable, not the duration of exposure in a defined timeframe, such as daily or weekly screen time.

Table 1: **Characteristics of studies on the association between smart device use and myopia included in the systematic review**

quota sampling[32] or convenience sampling from selected clinics[35,52] or schools,[21,30,36,39] which could have introduced selection bias.

Some studies recruited children aged younger than 7 years who might not yet have had enough time to develop myopia, given the disease's protracted natural history.[21,35]

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These studies did not account for the period during which myopia might have progressed in the future. By contrast, other studies investigated adults whose refraction had probably stabilised, and who were thus less susceptible to the environmental risk factors of myopia than children and adolescents.[28,36]

All 33 studies used questionnaires to measure smart device use, whereas one (3%) also used device-recorded network data consumption;[28] however, because different applications consume different quantities of network data, the reliability of this measure as an indicator of exposure is questionable (table 1). Studies tended not to account for the non-linear progression of myopia by age, with only one study[37] reporting the age of adoption of smart devices, and finding that adoption at younger ages (ie, ≤2 years) was significantly associated with myopia risk. Nine (27%) studies defined the study period during which exposure was measured (ie, the past week,[42,47,48] 2 weeks,[19] 1 month,[51] and 1 year[32,40,41,43]), but did not account for possible variations in screen time over long time periods.

All ten category one studies reported prevalent or incident myopia, although, only four (40%) studies[18,20,27,35] measured refraction. Among these four studies was the Growing Up in Singapore Towards healthy Outcomes (GUSTO) study,[35] which investigated early onset myopia (in participants aged ≤3 years) and found no increased risk with more screen time. However, each additional h per day of screen time was associated with a 0·7 mm (95% CI 0·01 to 0·13) increase in axial length and marginally increased myopic spherical equivalent (–0·10 dioptres [95% CI –0·20 to 0·0]), suggesting that children with longer screen time were at greater risk of incident myopia but were still too young for the condition to have developed. Similarly, there were no associations between prevalent myopia and screen time among children aged 6–14 years in Tianjin, China.[20] Each additional h per day of smartphone screen time was associated with longer axial length (0·10 mm [95% CI 0·07 to 0·39]) and an increased myopic spherical equivalent (–0·07 dioptres [95% CI –0·55 to –0·01]). These early trends in axial length and myopic spherical equivalent could indicate significant associations with incident myopia at follow-up.

In almost 20 000 Chinese children from rural areas, the prevalence of myopia was 18–20% in those who used smartphones for 1 min per day to more than 60 min per day, which was not significantly higher than the prevalence of myopia among those who reported no use of smartphones (18%); although, smartphone use for more than 60 min per day was associated with reduced uncorrected visual acuity.[27] However, the age-specific prevalence of myopia in this study was lower than in the general Chinese population,[57] and screen-time categories did not reflect the real-world use of smartphones, which could be as high as 8 h per day,[58] and the rural environ—ment might have been a protective factor against myopia.[59] By contrast, in a study of Irish children, when a category of longer smartphone screen time duration was used (ie, >3 h per day) and children from urban areas were included, myopia was considerably more prevalent with increased screen time.[18]

The remaining six (60%) of ten category one studies[23,28,32,36–38] relied on self-reported or parental-reported myopia, or visual inspection of spectacles by a study investigator to identify myopia.[28] Although smartphone screen time was neither associated with myopia among German[38] nor Chinese students,[36] each additional min per day was associated with a 2·6% increased risk of myopia among Irish students.[28]

Eight (80%) of ten category two studies[19,22,29,30,39,40,41,43] measured refraction, with the remaining two studies using either self-reported myopia[42] or optical biometry to measure axial length.[21] Six (60%) of ten studies[19,21,29,30,39,42] reported that digital screen use was associated with myopia or increased axial length, whereas three (30%) studies[22,40,43] reported no association. Two (20%) studies involving individuals aged 5–15 years in north India revealed some of the most significant associations between screen time and myopia; on the one hand, more than 2 h per day of screen time was associated with 8·33-times higher odds of myopia compared with less than 2 h per day among children at private schools,[30] and, on the other hand, more than 4 h per week of screen time was associated with 8·10-times higher odds of myopia compared with no screen time among children from ten randomly selected schools.[29] The prevalence of myopia was as high as 37–44% among Danish teenagers who used digital screens for more than 6 h per day compared with only 0–0·6% among those who used digital screens for less than 0·5 h per day.[19]

Any digital screen exposure in the past year was associated with a lower odds of myopia compared with no exposure in the past year among Taiwanese children.[41] Regression analysis showed no difference in the myopic spherical equivalent between these two groups,[41] and screen exposure was not significantly associated with myopia progression at follow-up.[40]

All 13 category three studies measured refraction, and most (seven [54%]) found no association between the duration of near-vision work and either myopia[44,49–51,53] or spherical equivalent.[46,49,50,56] Each additional h per week of near-vision work (ie, use of a smartphone, computer, or television, or reading books or studying) was associated with a 1% increase in the odds of myopia[47] and a 26% increase in the odds of severe myopia[48] in two nationwide Taiwanese studies, respectively. The prevalence of myopia in Italian children who played video games for 30 min per day or more and used digital devices for 3 h per day or more was 6·8%, compared with a prevalence of 0% among those who played video games for less than 30 min per day and used digital devices for less than 3 h per day, although no statistical associations were provided.[52]

	Screen exposure measure (number of participants)	Adjusted factors	Published outcome	OR (95% CI) in meta-analysis
Cross-sectional studies				
Guan et al (2019)[27]	Smartphone screen time: 0 min per day (n=13 161); 1–30 min per day (n=5360); 31–60 min per day (n=829); and >60 min per day (n=584)	Age, sex, family wealth, parental migrant status, parental education, child's residence, and correlation between eyes	0 min per day β coefficient 1 (ref); 1–30 min per day 0·03 (95% CI –0·07–0·12); 31–60 min per day –0·02 (–0·22–0·19); and >60 min per day 0·16 (–0·07–0·39)	0 min per day 1 (ref); 1–30 min per day 1·03 (0·94–1·12); 31–60 min per day 0·99 (0·81–1·20); and >60 min per day 1·17 (0·93–1·48)*
Harrington et al (2019)[18]	Smartphone screen time <1 h per day (n=313); 1–3 h per day (n=707); and >3 h per day (n=582)	Age and ethnicity	<1 h per day OR 0·30 (95% CI 0·20–0·50); 1–3 h per day 0·50 (0·30–0·80); and >3 h per day 1 (ref)	<1 h per day 1 (ref); 1–3 h per day 1·67 (1·00–2·67); and >3 h per day 3·33 (2·00–5·00)†
Toh et al (2019)[32]	Tablet screen time in h per day (n=1884)	Gender, grade at school, mental health score, amount of physical activity and total duration of technology use	OR 0·99 (95% CI 0·94–1·05)	0·99 (0·94–1·05)
Liu et al (2019)[20]	Tablet screen time in h per day (n=566)	Not stated (multivariable)	OR 1·40 (95% CI 0·86–2·28)	1·40 (0·86–2·28)
McCrann et al (2020)[28]	Smartphone screen time in min per day (n=396)	Age, myopia status of parents, sex, and belief that technology can negatively affect eyes	$OR_{\text{min per day}}$ 1·03 (95% CI 1·00–1·05)	$OR_{\text{h per day}}$ 4·66 (1·08–20·13)
Hagen et al (2018)[22]	Screen time in h per day (n=898)	Sex	OR 1·01 (95% CI 0·78–1·31)	1·01 (0·78–1·31)
Saxena et al (2015)[29]	Mobile, computer, and video game screen time: <1 h per week (n=186); 1–4 h per week (n=1383); and >4 h per week (n=881)	Age, sex, school, family myopia, maternal education, socioeconomic status, near work time, TV time and outdoor time	<1 h per week OR 1 (ref); 1–4 h per week 4·50 (2·33–8·98); and >4 h per week 8·10 (4·05–16·21)	<1 h per week 1 (ref); 1–4 h per week 4·50 (2·29–8·83); >4 h per week 8·10 (4·05–16·20)
Singh et al (2019)[30]	Mobile and video game screen time: 0–2 h per day (n=1061); and >2–4 h per day (n=155)	sex, age, family history, spherical equivalent, outdoor time, study hours, video game time	0–2 h per day OR 1 (ref); and >2–4 h per day 8·33 (3·54–19·58)	0–2 h per day 1 (ref); >2–4 h per day 8·33 (3·54–19·59)
Prospective studies				
Chua et al (2015)[35]	Smart device screen time in h per day (n=541)	Age, sex, ethnicity, and maternal education	OR 1·04 (0·67–1·61)	1·04 (0·67–1·61)
Toh et al (2020)[23]	Tablet screen time in h per day (n=1413)	Gender, school level, musculoskeletal symptoms in the past month or visual health measures, mental health, physical activity, and total technology use	OR 0·98 (0·87–1·1)	0·98 (0·87–1·1)
Hansen et al (2020)[19]	Smartphone, tablet, or computer screen time on a weekday: <2 h per day (n=127); 2–4 h per day (n=360); 4–6 h per day (n=470); and >6 h per day (n=478)	Age, sex, weight, height, and physical activity	<2 h per day OR 1 (ref); 2–4 h per day 1·89 (1·09–3·28); 4–6 h per day 1·68 (0·98–2·89); and >6 h per day 1·89 (1·10–3·24)	<2 h per day 1 (ref); 2–4 h per day 1·89 (1·09–3·28); 4–6 h per day 1·68 (0·98–2·88); and >6 h per day 1·89 (1·10–3·24)

OR=odds ratio. *For all values, ORs were derived through transformation of reported β coefficients. †For all values, ORs were reversed to convert lowest screen time to referent for inter-study consistency.

Table 2: **Results from articles reporting associations between digital smart device use and incident or prevalent myopia included in meta-analysis models**

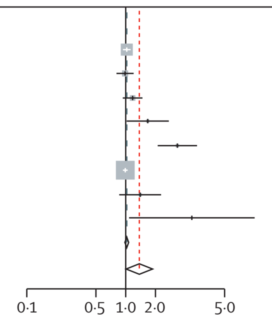
The ORs included in the meta-analysis models are presented in table 2. The meta-analysis of seven (70%) of ten category one studies (n=12 495) reporting associations between smart device screen time and myopia[18,20,23,27,28,32,35] produced a pooled OR of 1·26 (95% CI 1·00–1·60), suggesting that more smart device screen time is associated with myopia (figure 2). This association was conserved for cross-sectional category one studies (five studies [n=10 651]; 1·37 [1·01–1·87]), but not for the prospective category one studies (two studies [n=1954]; 0·98 [0·88–1·10]).

After pooling data from all 11 relevant category 1 and 2 studies[18–20,22,23,27,28,29,30,32,35] (n=13 968), a significant association between screen time on smartphones or tablets, or both, either alone or in combination with computer screen time, and myopia was observed (OR 1·77 [95% CI 1·28–2·45]). Although this significant association was maintained after pooling ORs from only cross-sectional category one and two studies (eight studies [n=13 968]; 2·01 [1·27–3·19]), no significant association was found among only prospective category one and two studies (three studies [n=3262]; 1·34 [0·98–1·83]).

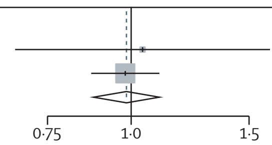
Figure 2: **Forest plots showing the association between smart device screen time and myopia**
(A) Associations between smart device screen time (category one articles only) and prevalent myopia. For cross-sectional and prospective studies combined, all studies were re-weighted to sum to 100%, and their weights displayed for the random-effects model. (B) Associations between smart device or computer screen time, or both (category one and two articles) and prevalent or incident myopia. Studies were not re-weighted to sum to 100% because both cross-sectional and prospective models used random-effects models, and the sum of their combined weights equalled 100%. ORs for categorical variables represent the relative odds for prevalent or incident myopia associated with each screen time category compared with the reference category (OR=1), as shown in table 2. OR=odds ratio. *Objective measurement of myopia. †Subjective measurement of myopia.

A

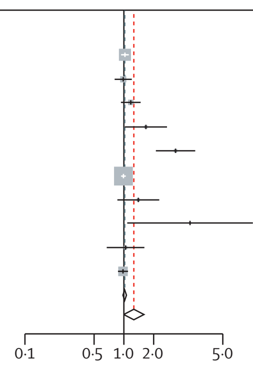
	Screen-time category	Participants	log (OR)	SE	OR (95% CI)	Weight
Cross-sectional studies						
Guan et al (2019)[27]*	1-30 min per day	5360	0·02	0·05	1·03 (0·94–1·12)	15·9%
Guan et al (2019)[27]*	31-60 min per day	829	−0·02	0·10	0·99 (0·81–1·20)	15·1%
Guan et al (2019)[27]*	>60 min per day	584	0·16	0·12	1·17 (0·93–1·48)	14·8%
Harrington et al (2019)[18]*	1-3 h per day	707	0·51	0·25	1·67 (1·02–2·73)	11·4%
Harrington et al (2019)[18]*	>3 h per day	582	1·20	0·23	3·33 (2·11–5·27)	11·9%
Toh et al (2019)[32]†	Per h per day	1833	−0·01	0·03	0·99 (0·94–1·05)	16·0%
Liu et al (2019)[20]*	Per h per day	360	0·34	0·25	1·40 (0·86–2·28)	11·5%
McCrann et al (2020)[28]*	Per h per day	364	1·54	0·75	4·66 (1·08–20·13)	3·5%
Random-effects model					**1·37 (1·01–1·87)**	**100·0%**
Heterogeneity I^2=82%; τ^2=0·15; p<0·001						



	Screen-time category	Participants	log (OR)	SE	OR (95% CI)	Weight
Prospective studies						
Chua et al (2015)[35]*	Per h per day	541	0·04	0·22	1·04 (0·67–1·61)	6·7%
Toh et al (2020)[23]†	Per h per day	1413	−0·02	0·06	0·98 (0·87–1·10)	93·3%
Fixed-effects model					**0·98 (0·88–1·10)**	**100·0%**
Heterogeneity I^2=0%; τ^2=0; p=0·80						

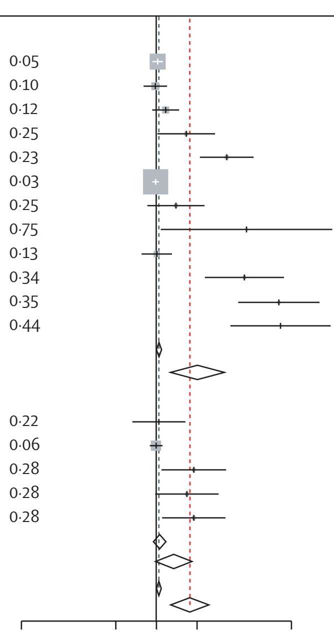


	Screen-time category	Participants	log (OR)	SE	OR (95% CI)	Weight
Cross-sectional and prospective studies						
Guan et al (2019)[27]*	1-30 min per day	5360	0·02	0·05	1·03 (0·94–1·12)	13·0%
Guan et al (2019)[27]*	31-60 min per day	829	−0·02	0·10	0·99 (0·81–1·20)	12·1%
Guan et al (2019)[27]*	>60 min per day	584	0·16	0·12	1·17 (0·93–1·48)	11·8%
Harrington et al (2019)[18]*	1-3 h per day	707	0·51	0·25	1·67 (1·02–2·73)	8·4%
Harrington et al (2019)[18]*	>3 h per day	582	1·20	0·23	3·33 (2·11–5·27)	8·8%
Toh et al (2019)[32]†	Per h per day	1833	−0·01	0·03	0·99 (0·94–1·05)	13·2%
Liu et al (2019)[20]*	Per h per day	360	0·34	0·25	1·40 (0·86–2·28)	8·5%
McCrann et al (2020)[28]*	Per h per day	286	1·54	0·75	4·66 (1·08–20·13)	2·2%
Chua et al (2015)[35]*	Per h per day	541	0·04	0·22	1·04 (0·67–1·61)	9·1%
Toh et al (2020)[23]†	Per h per day	1413	−0·02	0·06	0·98 (0·87–1·10)	12·9%
Random-effects model					**1·26 (1·00–1·60)**	**100·0%**
Heterogeneity I^2=77%; τ^2=0·11; p<0·001						



B

	Screen-time category	Participants	log (OR)	SE	OR (95% CI)	Weight
Cross-sectional studies						
Guan et al (2019)[27]*	1-30 min per day	5360	0·02	0·05	1·03 (0·94–1·12)	6·8%
Guan et al (2019)[27]*	31-60 min per day	829	−0·02	0·10	0·99 (0·81–1·20)	6·7%
Guan et al (2019)[27]*	>60 min per day	584	0·16	0·12	1·17 (0·93–1·48)	6·7%
Harrington et al (2019)[18]*	1-3 h per day	707	0·51	0·25	1·67 (1·02–2·73)	5·9%
Harrington et al (2019)[18]*	>3 h per day	582	1·20	0·23	3·33 (2·11–5·27)	6·1%
Toh et al (2019)[32]†	Per h per day	1833	−0·01	0·03	0·99 (0·94–1·05)	6·9%
Liu et al (2019)[20]*	Per h per day	360	0·34	0·25	1·40 (0·86–2·28)	6·0%
McCrann et al (2020)[28]*	Per h per day	364	1·54	0·75	4·66 (1·08–20·13)	2·9%
Hagen et al (2018)[22]*	Per h per day	393	0·01	0·13	1·01 (0·78–1·31)	6·6%
Saxena et al (2015)[29]*	1-4 hours/week	1383	1·50	0·34	4·50 (2·29–8·83)	5·3%
Saxena et al (2015)[29]*	>4 hours/week	881	2·09	0·35	8·10 (4·05–16·20)	5·2%
Singh et al (2019)[30]*	>2 hours/week	155	2·12	0·44	8·33 (3·54–19·59)	4·7%
Random-effects model					**2·01 (1·27–3·19)**	**69·7%**
Heterogeneity I^2=90%; τ^2=0·58; p<0·001						
Prospective studies						
Chua et al (2015)[35]*	Per h per day	541	0·04	0·22	1·04 (0·67–1·61)	6·1%
Toh et al (2020)[23]†	Per h per day	1413	−0·02	0·06	0·98 (0·87–1·10)	6·8%
Hansen et al (2020)[19]*	2–4 h per day (weekdays)	360	0·64	0·28	1·89 (1·09–3·28)	5·7%
Hansen et al (2020)[19]*	4–6 h per day (weekdays)	470	0·52	0·28	1·68 (0·98–2·88)	5·8%
Hansen et al (2020)[19]*	>6 h per day (weekdays)	478	0·64	0·28	1·89 (1·10–3·24)	5·8%
Random-effects model					**1·34 (0·98–1·83)**	**30·3%**
Heterogeneity I^2=70%; τ^2=0·08; p=0·01						
Random-effects model					**1·77 (1·28–2·45)**	**100·0%**
Heterogeneity I^2=87%; τ^2=0·40; p<0·001						



Discussion

This systematic review and meta-analysis provides some evidence to suggest that smart device exposure could be associated with myopia. However, the paucity of studies that used objective and standard measures of screen time and myopia, or that investigated smartphones and tablets independently, necessitates further research.

The fact that most studies did not categorise smart devices as an independent risk factor is understandable, given the recent introduction of these devices over the past 13 years and the convention for much of the previous literature to have grouped diverse behaviours into so-called near-vision work.[60] However, because of the longer viewing durations and closer viewing distances associated with smart devices than with books and other non-digital reading materials,[61] we recommend that future studies aim to investigate smart devices independently to better understand their effects on ocular health.

Most studies that investigated smart devices independently did not use objective clinical measures of myopia. Given the questionable sensitivity (76%) and specificity (74%) of self-reporting for myopia,[62] these findings should be considered cautiously. Those studies that did measure refraction objectively had inconsistent findings. For instance, although screen time was not associated with spherical equivalent, it predicted reduced visual acuity in one Chinese study,[27] whereas in another study,[20] increased screen time was associated with greater axial length and more myopic spherical equivalent, but not prevalent myopia. Further research might elucidate whether these subtle biometric associations portend clinically significant myopic shifts, such as those observed in Irish children, in whom more than 3 h per day of smartphone use was associated with three-times higher odds of myopia.[18]

Category two studies tended to report stronger associations between digital screen exposure and myopia than category one studies, including in two Indian studies that reported a 4–8 times higher risk of myopia.[29,30] This finding could suggest that computer screens are more myopigenic than smart devices; although, because these devices were not investigated separately, strong inferences cannot be made. Policy makers and parents should consider the amount of time spent using computers and smart devices in myopia control strategies. Due to the digitisation of education, controlling computer screen time could be more challenging than for smart devices, which tend to be used for leisure.

The meta-analysis results suggested that screen time on smartphones or tablets, or both, either alone or in combination with computer screen time was associated with myopia when cross-sectional and prospective studies were combined or when cross-sectional studies were analysed alone; however, the heterogeneity implicit in these analytical models warrants cautious interpretation of the results. The small number of prospective studies severely limits interpretation of the absence of an association in their pooled estimates. Nonetheless, one previous meta-analysis found that each additional h per week of near-vision work increased the odds of myopia by 2%.[60] Given that smart devices are used for longer durations and at closer distances than other forms of near-vision work,[9,10] it is possible that they could be similarly myopigenic.

This review differed from the systematic review by Lanca and Saw (2020) in several ways.[24] For reasons that are unclear, key studies included in our review that reported significant associations between screen time and myopia[18,19,30,37,42] were excluded from their review. Also noteworthy is that the authors weighted the non-significant OR of just one study[35] to account for 98·7% of the variance in the pooled OR, whereas we used a random-effects meta-analysis to accommodate high heterogeneity and permit all studies to influence the model. Finally, some of the non-significant ORs in their model were derived from transformations of significant ORs in source articles, which probably contributed to the observed absence of an association in their meta-analysis.

It can be argued that the associations reported in observational studies do not reveal causal links, and that the causal direction can be reversed, such that people with myopia are predisposed to spend more time on smart devices because their existing impairment renders distance viewing more demanding. However, there are several plausible mechanistic explanations that substantiate a unidirectional causal association between screen time and myopia. These explanations include those that apply to near-vision tasks generally, including the axial elongating effects of excessive accommodative convergence and peripheral defocus,[28] as well as the fact that the small screens and the font size of smart devices promote even closer viewing distances, placing greater demand on accommodation and vergence than conventional print materials.[10] Additionally, because screen use usually occurs indoors, the corresponding reduction in exposure to protective aspects of outdoor environments, such as higher luminosity and more uniform dioptric space could further disrupt emmetropisation.[63] This disruption could be caused, in part, by the inhibition of sunlight-induced retinal dopaminergic neurotransmission, a process that is instrumental in regulating normal refractive development.[64] Mendelian randomisation has provided strong unidirectional evidence that education, which involves a substantial amount of near-vision work, might be a cause of myopia, thus lending theoretical support to a potential influence of smart device use.[65] However, exploring these mechanistic explanations was beyond the scope of this study.

The key strengths of this study included the investigation of smart devices, both alone and in combination with other types of digital screens, to better discriminate the associations between the use of each type of device and myopia. Another strength is the comprehensive systematic component of the literature review, which identified significant methodological issues that, if addressed in future research, could facilitate a better understanding of the association between digital device use and myopia. There were also several limitations of the study. As most studies were done in Asian populations, it is not clear whether the results are generalisable to all populations. Additionally, because fewer than one-third of studies distinguished smart device screen time from other near-vision tasks, and because inter-study heterogeneity necessitated the construction of several meta-analysis models, strong conclusions about the link between smart device exposure and myopia cannot be drawn. In addition, all studies included in our study were limited by the use of parental-reporting or self-reporting to measure the amount of digital screen exposure, apart from in the study by McCrann and colleagues,[28] which attempted to provide objective measures through device-recorded network data consumption. Given that people tend to underestimate their own digital screen time (by as much as 40%),[66] future studies would benefit from using objective measures of screen time to eliminate recall bias. One solution could be to exploit the digital devices' own technology by installing an application on children's devices that tracks real-time use, permitting precise investigation of the dose-dependent influence of device use on the incidence and progression of myopia in longitudinal studies. Objective measurements of face-to-screen proximity, ambient light, and posture and viewing angle, as well as the types of applications used, could further elucidate the mechanisms by which digital device use might influence myopia. A randomised-controlled trial that reduces digital screen time as an intervention would permit robust causal inference. In future prospective studies, it would be important to follow participants until refractive stabilisation to account for later onset or progressive myopia, which was likely to have been missed in studies included in our review.

In conclusion, this systematic review and meta-analysis shows that there is insufficient and conflicting literature on the association between smartphone and tablet exposure and myopia, which is unsurprising given their relatively recent introduction. The results of the meta-analysis suggested that smart device screen time, alone and in combination with computer screen time, could be associated with an increased risk of myopia. As children continue to adopt digital devices at ever younger ages and their screen time increases, there is a pressing need for researchers to investigate the effects of these devices on eye health in diverse populations, and to use objective measures and clear and standardised categories of device exposure to better understand the role it might play in the escalating myopia epidemic. A better understanding of the association between digital screen exposure and myopia will be important for informing parenting, education, clinical practice guidelines, and public health policy.

Contributors

JF, ATS, and MD conceived the study. JF and ATS wrote the initial protocol, did the literature search, and screened articles. JF wrote the initial manuscript. JF, ATS, and AP organised the data and constructed tables. ATS, DF, and JF did the statistical analysis. All authors provided crucial feedback on the study protocol and contributed important intellectual content to the manuscript, including revisions. All authors had access to all the data in the study and had final responsibility for the decision to submit for publication. JF, ATS, DF, and DSWT have verified the data, with DSWT being independent of Plano.

Declaration of interests

JF, ATS, and DF are employees of Plano. AP was an employee of Plano at the time of writing. JC is a shareholder in Plano. MD is the co-founder, a shareholder, and the current managing director of Plano. Plano is a health technology start-up that was created as part of the Singapore Eye Research Institute-Singapore National Eye Centre Ophthalmic Technologies Incubator Programme to develop evidence-based technological and educational solutions to address the global burden of myopia. In accordance with policies of the Singapore National Eye Centre, TYW has received grants, contracts, consulting fees, honoraria, and travel support from, and has participated on advisory boards for Allergan, Bayer, Boehringer Ingelheim, Eden Ophthalmic, Genentech, Iveric Bio, Merck, Novartis, Oxurion (ThromboGenics), Roche, Samsung, Shanghai Henlius, and Zhaoke Pharmaceutical. TYW is the co-founder of Plano and EyRiS. The commercial relationships have not influenced the methods used in this study. All evidence has been presented and appraised in a balanced manner, and all data have been collected and analysed rigorously and without bias. DSWT, MGH, and RRAB declare no competing interests.

Data sharing

The extracted data for all the included studies in the meta-analysis and the analysis codes are available online at: https://github.com/dwightfonseka/metaanalysis.

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