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Review Article

A systematic review of near work and myopia: measurement, relationships, mechanisms and clinical corollaries

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ABSTRACT.
After decades of investigation, the role of near work in myopia remains unresolved, with some studies reporting no relationship and others finding the opposite. This systematic review is intended to summarize classic and recent literature investigating near work and the onset and progression of myopia, potential mechanisms and pertinent clinical recommendations. The impact of electronic device use is considered. PubMed and Medline were used to find peer-reviewed cross-sectional and longitudinal studies related to near work and myopia from 1980 to July 2020 using the PRISMA checklist. Studies were chosen using the Joanna Briggs Institute checklist, with a focus on studies with a sample size greater than 50. Studies were independently evaluated; conclusions were drawn per these evaluations. Numerous cross-sectional studies found increased odds ratio of myopia with increased near work. While early longitudinal studies failed to find this relationship, more recent longitudinal studies have found a relationship between myopia and near work. Rather than daily duration of near work, interest has increased regarding absolute working distance and duration of continuous near viewing. Several reports have found that shorter working distances (<30 cm) and continuous near-work activity (>30 min) are risk factors for myopia onset and progression. Novel objective continuously measuring rangefinding devices have been developed to better address these questions. The literature is conflicting, likely due to the subjective and variable nature in which near work has been quantified and a paucity of longitudinal studies. We conclude that more precise objective measures of near viewing behaviour are necessary to make definitive conclusions regarding the relationship between myopia and near work. Focus should shift to utilizing objective and continuously measuring instruments to quantify near-work behaviours in children, followed longitudinally, to understand the complex factors related to near work. A better understanding of the roles of absolute working distance, temporal properties, viewing breaks and electronic device use on myopia development and progression will aid in the development of evidence-based clinical recommendations for behavioural modifications to prevent and slow myopia.

Key words: near work – nearsightedness – myopia – refractive error – risk factors – objective devices – digital devices

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Introduction

The eye's refractive power is a result of the cornea, lens and axial length; when these components are mismatched, refractive errors result, including nearsightedness (myopia) or farsightedness (hyperopia). Myopia, in particular, is forecast to affect over 4.7 billion people or 49.8% of the world's population by 2050 (Holden et al. 2016). High myopia (−5.00 D or less) is predicted to affect 938 million people by 2050 (Holden et al. 2016). In parts of East and Southeast Asia, myopia affects nearly 80%–90% of young adults, with 10%–20% of young adults suffering from high myopia (Morgan et al. 2018). Myopia has been linked to numerous forms of ocular pathology, such as cataract, retinal detachment, macular holes, choroidal thinning and increased risk of glaucoma. These associations are generally much stronger for high myopia (Ikuno 2017). The economic costs of myopia are significant. In the United States, the National Health and Nutrition Examination Survey (NHANES) reported the annual direct cost of correcting distance vision impairment to be at least $3.8 billion USD (Vitale et al. 2006). Myopia is a global epidemic and public health concern.

Of interest to this review, accumulating evidence suggests that behavioural and environmental factors play a major role in eye growth and myopia development. Time outdoors (Rose et al. 2008; Wu et al. 2013; Read et al. 2014), near work (Konstantopoulos et al. 2008; Huang et al.

2015), education (Mirshahi et al. 2014; Han et al. 2019; Nickels et al. 2019) and urbanization (Rudnicka et al. 2016) are all potential influences for myopia onset and progression. Controversy remains as to how much, if at all, each of these factors contributes to myopia. Regarding near work, some studies show that associations with myopia exist (Pärssinen et al. 1989; Mutti et al. 2002; Lee et al. 2013; Hung et al. 2020), and other studies conclude the opposite (Jones et al. 2007; Lin et al. 2014; Yam et al. 2020). A 2015 meta-analysis of near work including 12 cohort studies and 15 cross-sectional studies found more time spent on near work activities was associated with higher odds ratio of myopia (OR 1.14) and a 2% increase in the odds of myopia for every one dioptre hour more of near work per week (Huang et al. 2015).

This systematic review is intended to summarize the early literature and discuss recent findings related to near work and myopia to clarify the current state of understanding on the topic for eye care practitioners and researchers. The review will detail the measurement and quantification of near work, the relationship between near work and myopia onset and progression, and potential mechanisms by which near work might influence eye growth. Throughout this review, we consider the distinction between studies that assess the association of near work and myopia prevalence (as examined in cross-sectional studies) and progression (examined in longitudinal studies). We also discuss clinical recommendations for behavioural modifications and future directions in this area of research.

Methods

A systematic review of the literature was conducted using methods developed in the Cochrane Handbook for Systematic Reviews (Higgins & Thomas 2019). PubMed and Medline were used to find peer-reviewed cross-sectional and longitudinal studies from 1980 to July 2020 using the following search terms: myopia, schoolchildren, prevalence, refractive error, risk factors, near work, screen time, electronic device use and accommodation. The reference lists of relevant publications were also considered as a source of additional articles. Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) checklist was followed. Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) is an evidence-based minimum set of items for reporting in systematic reviews or meta-analyses. We have classified the current report as a systematic review, which has been registered with PROSPERO (ID CRD42020203806). Studies were chosen using the Joanna Briggs Institute checklist, with a focus on studies with a sample size greater than 50. Near-work behaviours in chosen studies were quantified primarily from questionnaires, although some studies were focused on cohorts with a particular education (i.e. law students or ultra-Orthodox education). Refraction for all studies was non-cycloplegic or cycloplegic refraction, except for two studies: in one, the classification of refractive status as myopic was not clarified (Zadnik & Mutti 1987), and in the second, classification as myopic was based on the need for distance correction (Huang et al. 2019) (see Table 2 for details). While cycloplegic refraction is the gold standard for accurate measures of refraction, particularly in children and young adults, studies that did not include cycloplegia are discussed in this review because they provide valuable behavioural information, and errors in classification as myopic are expected to be minimal. Articles were critically reviewed and independently evaluated, and conclusions were drawn per these evaluations. Odds ratio for myopia with near work is provided when available, and limitations are discussed.

Measurement and quantification of near work

In order to understand how near work might influence myopia, it is important to have reliable and accurate methods of quantification. A wide array of measurement methods have been used in the literature, including questionnaires, diaries and the experience sampling method. More recently, researchers have made use of wearable sensors to objectively quantify near work. These methods, as well as near-work metrics, are discussed below.

Subjective measurement techniques

The most common method used to measure near work in children is via parent questionnaire, in which parents are asked to estimate how much time a child spends reading, studying and watching television, among other activities. Parents are often asked to estimate times separately for weekdays versus weekend and school versus summer break. Sociodemographic information may be collected along with past medical and ocular history (Saw et al. 2002a; Ojaimi et al. 2005; Williams et al. 2019). Questionnaires offer the benefits of being cost effective and easy to widely administer. However, questionnaires present several limitations, most importantly, that they are subject to recall and parent biases (Whiteman & Green 1997; Najman et al. 2001), with one review of literature identifying 48 common types of bias present in questionnaires (Choi & Pak 2005). Another limitation of previous questionnaires is that surrogate measures were often used in lieu of near-work quantification, such as number of books read per week (Saw et al. 2002a, 2002b), grades (Saw et al. 2007), intelligence (Rosner & Belkin 1987) or occupation (Adams & McBrien 1992; Simensen & Thorud 1994). However, these surrogate measures may not have always intended to represent near-work quantification. Additionally, researchers must be careful in how questionnaires are structured to avoid ambiguous wordage, leading questions, inconsistencies, formatting discrepancies, excessive length and cultural biases (Choi & Pak 2005).

Some studies have utilized diaries to measure near work (Saw et al. 1999b; Tan et al. 2000; Scheiman et al. 2014). Diaries offer several benefits in near-work quantification, as they can minimize the recall bias that questionnaires suffer from. However, diaries are limited by subject compliance. Experiments testing the agreement of data acquisition between diaries and other methods provide insight into which methods are comparable. In a comparison between 24-h diary data and child-completed questionnaires, authors found significant differences between the two methods; near work estimated from diaries was 0.3 h per day more than that from questionnaires (Saw et al. 1999b).

One method of overcoming some of the limitations of questionnaires or diaries is the experience sampling method (Rah et al. 2001, 2004; Bullimore et al. 2006), which involves contacting subjects at specific times throughout the day so the subject can report the activities that are being performed at that particular moment. The usable response rate has been reported to be 81%–87% (Rah et al. 2006). With the exclusion of time spent in conversation, one study reported no significant differences found between visual activity from the experience sampling method and data from surveys (Rah et al. 2006). While the experience sampling method detects real-time sampling of activities, a limitation is that only discreet time-points can be sampled. Additionally, Rah et al. (2006) noted confusion from subjects when asked to report viewing distance estimates for far viewing activities, such as riding in a car or playing sports. For example, the viewing distances when looking out the window and driving differ from sitting in the passenger seat and reading a book or using a digital device.

Objective measurement techniques

Novel methods for near-work data collection include the use of wearable electronic monitoring devices to continuously and objectively record viewing distances (Figueiro et al. 2013). The Kinect sensor v1 (Microsoft Corp.), a commercially available device capable of obtaining depth information, has been used to map the dioptric scene viewed by the wearer. However, the device was unable to record distances closer than 30 cm (Garcia et al. 2018). Recently, rangefinding devices have been developed specifically for the purpose of myopia related research. Instruments such as the Clouclip and RangeLife are spectacle-mounted rangefinders that continuously record distance from the spectacles to a target that is along the axis of the instrument (Wen et al. 2019; Williams et al. 2019). These devices offer several advantages in that, in addition to being objective, other important near viewing behaviours, such as absolute distance and viewing breaks, can be derived from the data. The use of electronic monitoring devices has the ability to assess these diverse viewing behaviours (Williams et al. 2019). One limitation of these devices is that viewing targets cannot be identified, for example whether the wearer is viewing a printed book versus a handheld electronic device, which might be important to fully understand myopiagenic stimuli, as discussed below. Other considerations with wearable rangefinding devices are portability, ease of wear and potential effects on children's behaviours. For example, early devices consisted of headband and sensors that would not be feasible for children to wear (Leung et al. 2011). The RangeLife is mounted on spectacles, but necessitates a cord leading to a battery pack (Williams et al. 2019). The Clouclip is portable and wireless, but is not waterproof and cannot be worn for activities such as swimming, so all activities cannot be captured (Bhandari & Ostrin, 2020). Both the Clouclip and RangeLife are spectacle mounted, thus require emmetropic children to wear plano spectacles to mount the device. Children may alter their behaviours, knowing that their viewing activities are monitored. In addition to wearable devices, applications are being developed for handheld devices, which can measure face-to-screen distance (Salmeron-Campillo et al. 2019). Recent studies show these devices are accurate, consistent and feasible to use (Bhandari & Ostrin 2020; Wen et al. 2021). These instruments are still new, and more validation studies are needed to confirm the accuracy, reliability and utility of the data collected.

Near-work metrics

A simple method to quantify near-work data is to denote the hours per day a subject spends on certain tasks, such as reading or using a computer outside of school (Saw et al. 2001, 2002b). However, this simple quantification does not fully describe visual demand. For example, reading a book at 30 cm versus using a computer at 50 cm have different dioptric demands, and simply noting the hours a subject spends on a given activity does not consider this accommodative demand. A more descriptive metric is 'dioptre hours', in which near and intermediate activities are weighted based on accommodative demand (Saw et al. 1999a; Mutti et al. 2002). For example, time spent reading at a near distance is given more weight than using a computer at an intermediate distance. Table 1 summarizes various formulas that previous studies have used to calculate dioptre hours. Traditionally, 'dioptre hours' is a metric derived from questionnaires; however, the principle can be applied to objective methods as well. While more descriptive than simply tallying hours of near work, this metric on its own still cannot fully describe the complexity of other viewing behaviours that may influence eye growth, such as absolute viewing distance and viewing breaks (You et al. 2012; Williams et al. 2019). Additionally, there is no one formula that is used consistently across studies, as evident in Table 1. A modified version of the dioptre-hours formula, presented here, may be an ideal

Table 1. Dioptre-hour formulas used in various studies

Reference	Formula
Activities weighted by composite variable	
Mutti et al. (2002) Zadnik et al. (1994) Muhamedagic et al. (2014) Yam et al. (2020)	(3 × h studying/reading for pleasure) + (2 × h watching video/computer) + (1 × h watching television)*per week
Saw et al. (2002)	(3 × h reading) + (2 × h using a computer/video games)*per day
Lin et al. (2017)	(3 × h reading/drawing/writing/homework) + (2 × h using a computer/video games/toys/musical instruments/crafts) + (1 × h watching television)*per week
Ip et al. (2008)	(3 × h homework/reading/handheld games) + (2 × h playing musical instruments/using a computer/video games/board games)*per week
Activities weighted by accommodative demand	
Lu et al. (2009)	Accommodative demand (D) × hours spent in near work*per week
Saw et al. (1999a)	Accommodative demand (D) at which the activity was performed × duration of the activity*per day

method to quantify near work for weekdays (equation 1), weekends (equation 2) and a weighted mean dioptre hours (equation 3).

$$\begin{aligned}&\text{weekday dioptre hours (per one weekday)} =\\&(3 \times \text{hours reading/drawing/writing/homework}) + \\&(2 \times \text{hours using a computer/video games/toys/}\\&\text{musical instruments/crafts)}\\&+(1 \times \text{hours watching television})\end{aligned} \quad (1)$$

$$\begin{aligned}&\text{weekend dioptre hours (per one weekend day)} =\\&(3 \times \text{hours reading/drawing/writing/homework})\\&+(2 \times \text{hours using a computer/video games/toys/}\\&\text{musical instruments/crafts)}\\&+(1 \times \text{hours watching television})\end{aligned} \quad (2)$$

$$\begin{aligned}&\text{mean dioptre hours} =\\&((5 \times \text{ weekday dioptre hours})\\&+2 \times \text{ weekend dioptre hours})/7\end{aligned} \quad (3)$$

The formulas above encompass the different dioptric demands of various forms of near work and account for weekday-to-weekend variations which may exist. To illustrate, an individual may spend many hours in front of a computer during weekdays, but spend most the time outside on the weekend.

Association between near work and myopia

We will now review the literature regarding potential associations between near work and the prevalence and/or progression of myopia. Findings from landmark epidemiological studies are summarized, evidence from adult-onset myopia is presented, and more recent investigations regarding the influence of electronic device use in myopia are discussed. A summary of the major studies discussed in this review is shown in Table 2.

The orinda longitudinal study of myopia (OLSM) and the collaborative longitudinal evaluation of ethnicity and refractive error (CLEERE) study

The Orinda Longitudinal Study of Myopia (OLSM) began in 1989 and investigated normal eye growth and the development of myopia in over 1200 school-aged children. The Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study was a continuation of the OLSM, with additional ethnic representation among the participants. The OLSM and CLEERE study were cohort studies of school-aged children from grades 1–8 that aimed to determine valid predictors of myopic onset. Refractive, biometric and behavioural data were collected at five clinical sites: Orinda, CA; Eutaw, AL; Irvine, CA; Houston, TX and Tucson, AZ. Cross-sectional analysis from 8th grade students in the OLSM demonstrated that children with myopia were more likely to spend significantly more time studying and more time reading (Mutti et al. 2002). However, findings from the CLEERE study showed that the hazard ratio for dioptre hours was 1.00, meaning that near-work activities did not increase the risk of developing myopia (Jones-Jordan et al. 2010).

Further analysis of the longitudinal CLEERE data focused on near work and outdoor time up to 5 years before and 5 years after the onset of myopia and found that children who ultimately became myopic showed increased reading, studying, computer time and television compared with emmetropic children (Jones-Jordan et al. 2011). However, these increases were only observed at the year of myopia onset and thereafter. Dioptre hours was shown to increase one year prior to myopia onset compared with emmetropes. As significant differences in near-work behaviours were not present until the year of onset, the authors concluded that it is unlikely that increased near work is an important contributor to juvenile-onset myopia. Support for these conclusions is offered by a cross-sectional study of 1232 children in Xichang, China, that found no significant differences in time spent doing near work or dioptre hours for children with and children without myopia, following multivariate regression analysis (Lu et al. 2009). On the contrary, a 3-year longitudinal study in 240 Finnish children found that more time spent on reading and close work significantly contributed to faster myopic progression (Pärssinen et al. 1989). A difference between the CLEERE and Finnish studies was that the Finnish children spent about twice the amount of time in near work than children in the CLEERE study. A limitation of the CLEERE and ORINDA studies was that ethnic groups were predominantly recruited from particular study sites; therefore, it is difficult to determine whether behavioural differences are influenced by location or ethnicity.

The Singapore cohort study of the risk factors for myopia (SCORM) study

Children aged 7–9 years from three Singaporean schools were evaluated in the Singapore Cohort study Of the Risk factors for Myopia (SCORM) study. Initial cross-sectional analysis showed that children who read more than two books per week had longer axial lengths than those who read <2 books per week (Saw et al. 2002b). However, an important question is whether ‘books read per week’, is a suitable metric for quantifying near work. A later analysis was conducted on the myopic children (n = 543) in SCORM with 3-year follow-up data. The authors found no significant association between any form of near work and biometric parameter change (Saw et al. 2005). The authors proposed this disparity between cross-sectional and longitudinal findings could be attributed to narrow age range, young cohort, misclassification of near work and a difference in the role that near work plays in myopic onset versus progression (Saw et al. 2005). Additionally, when a subset of children in the SCORM study was analysed with age-matched Finnish children, findings showed that regardless of near work, younger age of myopia onset was the most significant factor predicting myopic progression (Pärssinen et al. 2021).

The Sydney myopia study and the Sydney adolescent vascular and eye study

The Sydney Myopia Study was a population-based cross-sectional study from 2003 to 2005, evaluating both a younger cohort (age 6 years) and older cohort (age 12 years) (Ojaimi et al. 2005; Ip et al. 2008). A 5- to 6-year longitudinal follow-up was conducted, known as the Sydney Adolescent Vascular and Eye Study (SAVES) (French et al. 2013). An analysis of the Sydney Myopia Study included 2339 Australian schoolchildren of the older cohort and investigated several factors related to near work, including not only the duration of near-work activities, but also estimates of reading distance and time spent in continuous

Table 2. Summary of findings from studies discussed in this review, presented in chronological order

Study or population of interest	Authors, year	Type of study (Length of Follow-up)	Age	Number of participants	Definition of myopia	Conclusion with respect to near work
Studies that report an association between myopia and near work						
Law students	Zadnik & Mutti (1987)	Retrospective survey and longitudinal (6 months)	Young adults	Survey: 87 longitudinal: 16	n/a	Students in law school experienced increased incident myopia (at least 1.9% of law students in 6 months) and myopic shifts (1.9–37.5% of law students in 6 months) compared to what would be expected generally for this age group, implicating intense near work in adult-onset myopia.
Finnish children	Pärssinen et al. (1989)	Longitudinal (3 years)	Mean: 10.9 years Range: 8.8–12.8 years	240	≤−0.35 D cycloplegic	The more the time spent on reading and close work the faster was the rate of myopic progression.
Adult microscopists	McBrien & Adams (1997)	Longitudinal (2 years)	Mean: 29.9 years Range: 21–63 years	166	≤−0.375D non-cycloplegic	Microscopy, a profession requiring intense near work, increases incident and prevalent myopia in adults. (following entry into the profession, 49% of adults reported myopic onset or progression).
Norway engineering students	Kinge et al. (2000)	Longitudinal (3 years)	Mean: 20.6 ± 1.1 years at baseline	224	≤0.25 D cycloplegic	Education requiring intense near work is associated with a myopic shift in refraction. Near work is associated with myopic shift in refraction ($p < 0.05$).
Orinda	Mutti et al. (2002)	Cross-Sectional	Mean: 13.7 ± 0.5 years	366	≤−0.75 D cycloplegic	Near work is an independent contributor to juvenile myopia (multivariate OR: 1.02 for each dioptre hour per week of near work).
SCORM	Saw et al. (2002)	Cross-Sectional	Range: 7–9	1453	≤0.5 D cycloplegic	Reading more than 2 books per week is associated with longer axial length (OR 2.81).
Sydney Myopia Study	Ip et al. (2008)	Cross-Sectional	Mean: 12.7 years Range: 11.1–14.4	2339	≤0.5 D cycloplegic	Longer time spent reading for pleasure and a closer reading distance (<30 cm) were associated with myopic progression after multivariate adjustment ((P (trend) = 0.02 and p = 0.0003, respectively).
SAVES	French et al. (2013)	Longitudinal	Range: 11–18 years	2103	≤0.5 D, cycloplegic	Near work in younger children contributes to incident myopia.
School-age students in Guangzhou	Guo et al. (2016)	Cross-Sectional	Mean: 13.6 ± 1.6 years	3055	≤0.5 D, cycloplegic	Longer time spent for near work and shorter distance of near work were shown to be associated with the increasing risk of myopia in children.
Polish school children	Czepita et al. (2017)	Cross-Sectional	Mean: 11.9 ± 3.2 years Range: 6–18	5601	≤0.5 D, cycloplegic	More time reading and writing ($p < 0.000001$), and working on a computer ($p < 0.000001$) is associated with higher myopia prevalence.
Ultra-Orthodox Education	Bez et al. (2019)	Cross-Sectional	Mean: 17.7 ± 0.06 years Range: 17–18	22 823	≤0.5 D, non-cycloplegic	Intense educational system is associated with myopia prevalence (multivariate OR for ultra-Orthodox educational system, 9.3; 95% CI, 8.2-10.7; P <.001).
Nanjing university students	Huang et al. (2019)	Cross-sectional	Mean: 19.6 ± 0.9 years	1153	Need for distance correction	Breaks after 30 min of continuous reading were protective against myopia (OR 0.61); near work duration was not associated with myopia.
Experimental Aviation Class	Yao et al. (2019)	Longitudinal (3 years)	Age range: 14–16 and non-myopic at baseline	800	≤0.5 D cycloplegic	Longer class time (OR = 3.2), frequent, continuous and long time reading/writing (OR = 1.62) and shorter reading/writing distance (OR = 1.83) contribute to incident myopia and myopic progression.
The Myopia Investigation Study	Huang et al. (2020)	Longitudinal (2 years)	Age range: 9–11	10 743	≤0.5 D cycloplegic	Longer near-work distance (RR 0.70) and discontinuing near-work (RR 0.77) deterred myopic onset. Near-work distance <30 cm (p = 0.001) and continuous near work >30 min (p = 0.02) increased myopic progression.

Table 2 (Continued)

Study or population of interest	Authors, year	Type of study (Length of Follow-up)	Age	Number of participants	Definition of myopia	Conclusion with respect to near work
Generation R	Enthoven et al. (2020)	Longitudinal *not all subjects had longitudinal data	Age range: 3–9	5074	≤0.5 D cycloplegic	The combined effect of near work (computer use, reading time and reading distance) showed an increased odds ratio for myopia at age 9 (OR = 1.07).
Studies that report weak or no association between myopia and near work						
Law students	Loman et al. (2002)	Retrospective survey	Range: 23–44 years	177	≤0.5 D non-cycloplegic	Weak nonsignificant trend between near work and myopia progression.
SCORM	Saw et al. (2005)	Longitudinal (3 years)	Range: 7–9	981	≤0.5 D cycloplegic	Reading in books per week is not associated with axial length change (p = 0.80).
The Xichang Pediatric Refractive Error Study Report No. 2	Lu et al. (2009)	Cross-Sectional	Mean: 14.6 ± 0.8 years Range: 13–17 years	1232	≤0.5 D cycloplegic	Time spent on near-work activities was not associated with myopia following multivariate adjustment (e.g. personal reading: multivariate OR 1.27; p = 0.38).
CLEERE	Jones-Jordan et al. (2011)	Longitudinal (up to 10 years)	Range: 6–14	1318	≤−0.75 D cycloplegic	Near work is not an important contributor to the onset of juvenile myopia, given significant increases in near work largely appear at and after myopic onset.
Beijing Myopia Progression Study	Lin et al. (2014)	Cross-Sectional	Range: 6–17 years	370	≤0.5 D, cycloplegic	Near-work activity was not found to be associated with refraction.

The first group of studies concluded that associations between myopia and near work exist, whereas the second group of studies concluded that there were weak or no associations between myopia and near work.

reading without a break. The authors found that a short reading distance (<30 cm) and continuous reading (>30 min) independently increased the odds of myopia (OR 2.5 and 1.5, respectively), even though overall time spent in near-work activities was not associated with myopia (Ip et al. 2008). According to these findings, the role of near work is dependent on the *nature* of the viewing behaviour, not simply duration. These findings suggest that viewing breaks and longer working distances may prove to be important behavioural modifications.

Sydney Adolescent Vascular and Eye Study (SAVES) re-examined 2103 children of the Sydney Myopia Study, 5–6 years later. Children in the younger cohort who became myopic performed significantly more near work per week (19.4 versus 17.7 h; p = 0.02); in the older cohort, the relationship between myopia and near work failed to reach significance (p = 0.06) (French et al. 2013). This is shown in Fig. 1, comparing the odds

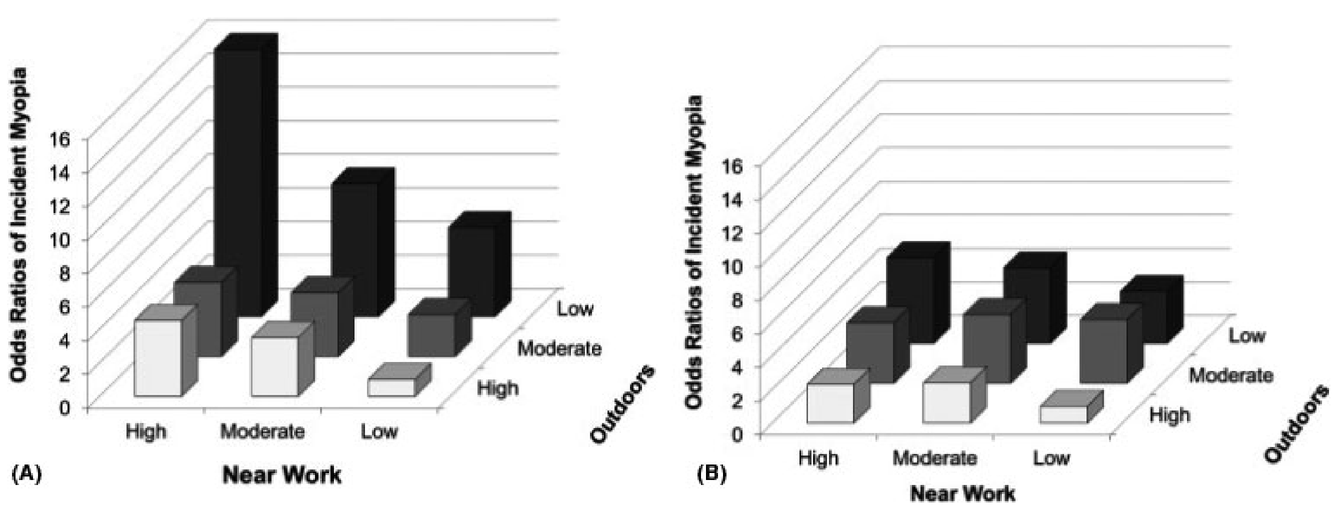

Figure 1. Odds ratios (calculated from multivariate logistic regression analysis and adjusted for parental myopia, age and sex) of incident myopia by tertiles of baseline time outdoors and near work in the (A) younger cohort and (B) older cohort. Reprinted from French AN et al. (2013) with permission from Elsevier.

ratio of myopia in the younger versus the older cohort, with low amounts of outdoor time coupled with high amounts of near work resulting in the largest odds ratio for both age groups (younger cohort OR 15.9; older cohort OR 5.1) (French et al. 2013). The results suggest that the impact of near work on myopia progression may be stronger in young children. These implications are supported by a recent study that showed learning to read at an earlier age was associated with myopia (Gordon-Shaag et al. 2021). While outdoor time had a stronger relationship than near work for incident myopia, increasing levels of near work increased the odds ratio in a stepwise fashion in the younger cohort (French et al. 2013).

In contrast to the SAVES study, a study that investigated students (6–17 years old) from schools in the inner city of Beijing (Lin et al. 2014) found no significant associations between near work (in hours/day) and refractive error following adjustment for gender, parental refractive error and time spent outdoors ($\beta = -0.03$, $p = 0.77$ and $\beta = -0.01$, $p = 0.93$, respectively). Children with high levels of near-work time did not exhibit more myopic refractive errors than those with moderate or low levels of near work for either primary or secondary school. This conclusion operates under the assumption that the estimates of near work were accurate. Considering children in East Asia often have a high amount of educational pressure, estimates of near work may have been clustered, and associations may have been difficult to detect.

Evidence from adult-onset myopia

Important insights have been gained from studies investigating adult-onset myopia. McBrien and Adams found nearly 50% of adults in clinical microscopy (a profession requiring intensive near work) suffered from adult-onset and/or myopia progression (McBrien & Adams 1997). A study of 177 law students found myopia worsened for 86.5% of the myopic subjects (Loman et al. 2002). Of students who were not myopic, 18.7% developed nearsightedness during law school, even those above the age of 30 shared similarly high rates of myopic progression. Despite these findings, the relationship between myopia progression and reported near work was not significant (Loman et al. 2002). In a study of first-year law students, Zadnik and Mutti found 12 eyes (37.5%) became at least −0.50 D more myopic in 6 months (Zadnik & Mutti 1987). Another study showed that more time spent reading scientific literature amounted to faster myopic progression for Norwegian engineering students (Kinge et al. 2000). These studies provide evidence that near work may be sufficient to cause myopia onset and progression in young adults; however, mechanisms are not well understood.

Recent findings

More recent longitudinal studies challenge the negative findings from the CLEERE and SCORM studies regarding the influence of near work on myopia. The Myopia Investigation Study in Taipei was a population-based cohort study that followed 9- to 11-year-old children ($n = 10\,743$) over 2 years (Huang et al. 2020). Following adjustment for gender and parental high myopia, students with near-work distance >30 cm and that discontinued near work every 30 min had significantly less myopic progression. These factors remained significant after adjustment for other behaviours, suggesting they are independent risk factors. The findings are in accordance with those reported by Ip et al. (2008) who similarly found that longer time spent reading for pleasure and a closer reading distance (<30 cm) were associated with myopic progression after multivariate adjustment ($p < 0.05$ for both). Another recent longitudinal study in aviation cadets in China included 800 non-myopic males (mean age 15 years) and found similar results (Yao et al. 2019). A comprehensive ocular examination and detailed questionnaire were given at baseline and each of two follow-up visits. Incident myopia was significantly associated with frequent, continuous and longer duration of reading/writing (OR 1.62) and shorter reading/writing distance (OR = 1.83). In a multiple linear regression model, longer reading/writing duration (over 1 h) and shorter reading/writing distances were risk factors for incident myopia.

Several recent cross-sectional studies also report relationships between near work and prevalent myopia. A study investigating 5601 Polish school children, aged 6–18 years, found more time spent reading and writing ($p < 0.001$) was associated with a higher prevalence of myopia (Czepita et al. 2017). Male adolescents (mean age 17.7 years) in Israel in three different educational systems, secular, Orthodox, and ultra-Orthodox, were assessed as a means to investigate the influence of near work on myopia; the ultra-Orthodox educational system is characterized by intense near-work activity (Bez et al. 2019). Following adjustment for age, country of origin, socioeconomic status, years of education and body mass index, analysis of 22 823 males found the adjusted odds ratio of myopia was 2.3 for Orthodox and 9.3 for ultra-Orthodox males, representing a significant association between near work and myopia in this population. A study of first-year university students in Nanjing found taking breaks after 30 min of continuous reading was protective against myopia in multivariate analysis (OR = 0.61) (Huang et al. 2019). Guo et al. (2016) reported that longer time spent for near work and shorter distance of near work was shown to be associated with the increasing risk of myopia in children.

Objective continuously measuring rangefinders have also shown that absolute distance is an important factor. Using an objective ultrasonic rangefinder, Leung et al. (2011) found that high myopes had a significantly shorter reading distance than low or non-myopes (36 cm versus 51 cm; $p = 0.04$); however, it is unclear whether these associations are causal or merely a result of higher degrees of myopia. Wen et al. (2020) used the ClouClip rangefinding device, and in a multivariate logistical analysis, reported that working distance <20 cm was an independent risk factor for myopia.

Electronic device use

There has been increasing interest in understanding the potential impact of electronic devices on myopia. Electronic device use, or screen time, is included in this review because the majority of screen time is carried out at near and intermediate working distances (<60 cm). In a 2017 report (Brooks & Pomerantz 2017), 97% of respondents reported owning a smartphone. In contrast, only 66% of respondents owned an Internet-capable handheld device in 2010 (Smith & Caruso 2010). Furthermore, the COVID-19 pandemic has shifted the educational and professional workspace virtually (Ting et al. 2020). Consequently, it is likely that smartphone, tablet and computer use is at an all-time high for both students and professionals.

Several studies have reported a relationship between screen time and myopia. The CLEERE study showed that myopic children used computers and played video games more than emmetropic children, but only after myopia onset (Jones-Jordan et al. 2011). A study in Polish children found that computer use significantly contributed towards myopia prevalence ($p < 0.001$) (Czepita et al. 2010), and a study in Danish teenagers showed that greater use of screen devices on weekdays and weekends increased the odds ratio for myopia (OR = 1.95 and 2.1, respectively) (Hansen et al. 2020). Guan et al. (2019) similarly found prolonged computer usage and excess cellphone use was associated with greater refractive error. Their population-based survey of 19 934 students found a significant association between prolonged computer use (>60 m/day) and smartphone use with greater myopia ($p = 0.001$). Enthoven et al. (2020) reported that the combined effect of near work, including computer use, reading time and reading distance, increased the odds of myopia at 9 years (OR = 1.07). While these studies imply a significant association between screen time and myopia, the myopia epidemic began before the ubiquitous device use. It is possible that screen time is only marginally worsening the epidemic of myopia that was in-place before digital devices became popular. Regardless, because of their wide popularity and availability, digital devices may represent a modifiable risk factor.

On the contrary, a 2019 systematic review that included 15 studies totalling 49 789 children aged 3–19 years reported that only 7 of the 15 studies found an association between screen time and myopia (Lanca & Saw 2020). Only 5 of the 15 studies were considered in the meta-analysis, in which a pooled odds ratio of 1.02 suggested that screen time was not associated with prevalent or incident myopia. The authors suggested that further studies with objective measures of screen time are necessary to fully assess the relationship between screen time and myopia. To date, only one published study has reported objective data for smartphone use (McCrann et al. 2021). Findings showed that there was a significant association between smartphone data usage and myopia (OR 1.08); myopes used twice as much smartphone data (1130.71 ± 1748.14 MB) than did non-myopes (613.63 ± 902.15 MB, $p = 0.001$).

Several studies have investigated associations between myopia and television. While television is generally not considered a near viewing activity, as it is typically carried out at distances of 0.5 m to upwards of 4 m, we have included a brief discussion because television is an example of one of the earliest forms of screen time. An inverse relationship between television and myopia progression has been reported, with faster progression in children that watched television 0.5–3 h per day compared with greater than 3 h per day (Pärssinen et al. 2014). Other studies report no association between television and myopia (Kinge et al. 2000; Czepita et al. 2010), and one study reported an association in girls only (Guo et al. 2016). Conflicting findings may be due to the wide range in viewing distances individuals use when watching television and variable accommodative demand; Qiang & Zhao (1991) reported that there was a close relationship between myopia and the distance in which television was watched.

Potential mechanisms

Here, we provide consideration of proposed mechanisms regarding how near work might influence eye growth and myopia development. These include optical and biomechanical properties related to accommodation, polarity of viewing material and temporal viewing properties.

Accommodation

Near work generally involves accommodative demands ranging from 2 to 6 D (Bao et al. 2015; Williams et al. 2019; Wen et al. 2020). When the accommodative response does not meet the accommodative demand, a lag of accommodation results. Some studies show that myopic children and adults have greater accommodative lag than emmetropes (Bullimore & Gilmartin 1988; Gwiazda et al. 1993). However, Pärssinen & Lyyra (1993) reported that accommodation was not associated with myopic progression. Authors of the CLEERE study suggested that accommodative lag is a consequence of myopia, not a causative factor (Mutti et al. 2006), as differences in accommodative lag between myopes and emmetropes were not significant prior to myopia onset. In another study in children, lag neither at the beginning nor at the end of a yearly progression interval was associated with annual myopia progression (Berntsen et al. 2011). More recently, a study found that accommodative accuracy and distance accommodation facility in myopic children do not contribute to myopia progression (Chen et al. 2020).

Cross-sectional studies in children (Gwiazda et al. 1999; Mutti et al. 2000) and adults (Rosenfield & Gilmartin 1987; Jiang 1995) have found associations between higher accommodative convergence/accommodation (AC/A) ratios and myopia. Collaborative longitudinal evaluation of ethnicity and refractive error (CLEERE) found high AC/A ratios were associated with myopia, often presenting as early as 4 years before myopic onset (Mutti et al. 2017). While the authors noted that an increasing AC/A ratio was an early sign of becoming myopic and was related to a greater accommodative lag, they concluded that a greater AC/A ratio did not affect the rate of myopia progression.

Considering the premise that factors relating to accommodation, such as defocus induced from accommodative lag, may contribute to myopia, studies have assessed the effectiveness of bifocal or progressive addition lenses in slowing myopia progression in children. A small but significant slowing of myopia progression was observed in children with accommodative esotropia wearing bifocals (Fulk et al. 2000). Gwiazda et al. (2003) reported a small but significant slowing of myopia progression after one year in children wearing progressive addition lenses; however, the effect did not increase over the next two years. Other studies found no effect of multifocal spectacles on myopia progression (Shih et al. 2001; Edwards et al. 2002). Pärssinen et al. (1989) reported the lowest myopia progression among myopic children who did not use spectacles in near vision, while bifocals did not decrease progression. The authors suggested that while myopia progression is connected to reading and close work, the effect was not due to diminished accommodation required when wearing a near add, and speculated that convergence may contribute to myopia progression rather than accommodation (Pärssinen et al. 1989).

Ciliary body anatomy and biomechanics

There is evidence that ciliary body anatomy and biomechanics are involved in myopia pathogenesis. Myopes have been shown to have a larger ciliary muscle, in both cross-sectional area and thickness (Oliveira et al. 2005; Bailey et al. 2008; Sheppard & Davies 2010; Buckhurst et al. 2013). A larger and more stiff ciliary muscle might create a distorting force on the growing eye and adversely affect accommodative function, and this impaired accommodative function may contribute to larger AC/A ratios observed in myopes (Mutti et al. 2017). Whether impaired accommodative function is a mechanism by which prolonged near work results in or progresses myopia has not yet been determined. Implications of this finding on myopia pathogenesis are not well understood.

Peripheral defocus

Relative peripheral hyperopic defocus has been hypothesized as an important factor in the role of near work in myopia (Smith et al. 2005; Mutti et al. 2011; Brennan & Cheng 2019). Peripheral visual signals have been shown to drive central refractive development in animals (Smith et al. 2005, 2009). Imposing myopic defocus on the retina has shown promise as a means of myopia control in animal models (Tse et al. 2007; Benavente-Perez et al. 2012; Armugam et al. 2014) and is the basis of many effective myopia control modalities, including orthokeratology and multifocal contact lenses (Cho & Cheung 2012; Lam et al. 2014; Chamberlain et al. 2019). However, some studies have refuted this hypothesis (Mutti et al. 2011, 2019; Atchison et al. 2015), with some suggesting that increased peripheral hyperopic defocus may be a consequence of axial elongation, rather than a cause (Mutti et al. 2006; Rotolo et al. 2017). Another proposed theory is alterations in retinal activity, as achieved by a high-contrast image, inhibits eye growth (Wallman & Winawer 2004; Atchison & Rosen 2016). Negative spherical aberration coupled with lag of accommodation degrades central and peripheral retinal image quality and thus may stimulate growth (Thibos et al. 2013).

Temporal viewing properties and polarity of reading material

Temporal integration in the context of near work may play a role in myopia. Research in animals suggests brief periods of unrestricted vision can counterbalance long intervals of exposure to myopiagenic visual stimuli (Smith et al. 2002; Zhu et al. 2003). These findings suggest that ‘viewing breaks’ could counteract the myopiagenic effects of near work, and results from studies in humans discussed above are in accordance with this hypothesis (Huang et al. 2019, 2020; Yao et al. 2019). It is possible that short periods of distance viewing following 30 min of intensive near work may overcome the myopiagenic effects of near work. Further research is needed to support this hypothesis.

Another recent area of interest relates to the polarity of viewing material, that is the colour and contrast of the text versus the background. Ganglion cells are not uniformly excited by homogenously illuminated regions in the visual field because of their organization into ON and OFF pathways (Aleman et al. 2018). Blockage or elimination of the ON channel stunted ocular growth and induced hyperopia in cats (Smith et al. 1991) and chickens (Crewther et al. 1996). Comparatively, the OFF retinal ganglions have a smaller dendritic field and smaller receptive field, and are about twice as plentiful in guinea pigs (Ratliff et al. 2010). Lack of functional OFF channels caused mice to develop similar amounts of deprivation myopia as a wildtype (Chakraborty et al. 2014). Aleman et al. (2018) aimed to quantify relative ON and OFF stimulus strengths to gain insight into their respective roles in humans. Authors found that white text on black paper overstimulated the ON pathways (and induced choroidal thickening), and black text on white paper overstimulated the OFF pathways (and induced choroidal thinning). Furthermore, it is worth noting that the ON bipolar cells stimulate dopamine release and would therefore be expected to slow the development of myopia. Manipulating these two pathways via the polarity of reading material may be a potential intervention for myopia (Aleman et al. 2018; Wang et al. 2019).

Conclusions

According to recent studies, the role of near work in myopia onset and progression may be related to the *nature* of near work, that is absolute working distances and temporal properties. Such findings highlight the importance of using continuous and objective instruments for precise quantification of near viewing behaviours. Although robust and consistent evidence-based behavioural modifications have not been established, current clinical recommendations to reduce myopiagenic influence of near work may be beneficial and certainly not harmful. Recent behavioural interventions include increased outdoor time, for example required outdoor recess during school, which have shown benefit in reducing incidence and progression of myopia (Wu et al. 2018). Increased time outdoors may help to decrease near work, as children are not generally performing near work during outdoor recess. A common clinical recommendation, likely developed from recent studies discussed above (Ip et al. 2008; Huang et al. 2019, 2020; Yao et al. 2019), is the rule of 30 s – working distances longer than 30 cm, and 30-s viewing breaks for every 30 min of near work.

In China, the Clouclip and similar devices are marketed as tools to protect children from myopic behaviours. The Clouclip signals the child (via vibration) and alerts parents (via an app) when a child’s viewing behaviours are deemed unhealthy (near-work distance <30 cm and >5 s; near-work distance <60 cm for >45 min). A primary school in China’s Baoji installed bars over each desk to prevent children from working too close to their materials. Educational websites geared towards parents, such as mykidsvision.org, include near work as a risk factor for myopia onset or progression.

Limitations of the current review include the following. The methodology chosen for this systematic review was to include as many studies as possible and gain a broad understanding of the topic. Previous meta-analyses utilized very specific criteria which resulted in some important cross-sectional and longitudinal studies being excluded. Even with our lenient inclusion criteria, there are still numerous studies that were not included in this systematic review. Chosen studies took into consideration a multitude of factors, including impact factor of the published journal, authors of the review, methodology and number of subjects. While this review extensively covers the topic of near work, it would be inaccurate to state this review achieves complete analysis.

Similarly, direct comparisons were unavoidably subjective and limited by the use of variable metrics and formulas to calculate near-work risk across studies. A meta-analysis synthesizes studies in an equal fashion, and conclusions are drawn based on objective data analysis; however, meta-analyses generally employ strict inclusion criteria and may not be representative of all studies. Meanwhile, a systematic review, which may include more studies, is heavily dependent on the authors to synthesize data and draw conclusions. Inherent biases and predispositions, while consciously suppressed, might influence the conclusions made.

In summary, the literature remains conflicting, but we have drawn the following conclusions. Many studies, including both cross-sectional and longitudinal design, do support a link between near work and myopia. Adult-onset myopia for individuals in near-work dominated education or profession provides strong evidence for a near-work component to myopia. Continuous reading (>30 min) without breaks and shorter working distance (<30 cm) are implicated in myopia onset and/or progression in several recent studies. Longitudinal studies utilizing objective and continuously measuring rangefinders may be the key to determine how near work impacts eye growth.

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