Role of Near Work in Myopia: Findings in a Sample of Australian School Children

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Purpose. To examine the association of time spent in near work and reading with spherical equivalent refraction (SER) in a population-based sample of 12-year-old Australian schoolchildren.

Methods. Data on the time spent in near-work or outdoor activities per week and estimates for the duration of continuous reading and reading distances, were collected in questionnaires (2353 participants, 75.3% response) in the Sydney Myopia Study between 2004 and 2005; 2339 children underwent a comprehensive eye examination, including cycloplegia.

Results. Longer time spent on reading for pleasure and reports of close reading distance (<30 cm) were associated with a more myopic refraction after adjustment for age, sex, ethnicity, and school type (P_{trend} = 0.02 and P = 0.0003, respectively). Time spent in individual near-work activities, however, correlated poorly with SER (all $r \leq 0.2$) and was not significant in multivariate analyses for myopia (SER ≤ -0.50 D), with adjustment for age, sex, ethnicity, parental myopia, school type, and outdoor activity. Children of European Caucasian ethnicity reported spending marginally less time in near work than children of East Asian ethnicity (26.0 h/wk vs. 32.5 h/wk, $P <$ 0.0001). East Asian ethnicity, however, was associated with substantially greater odds of having myopia (odds ratio [OR], 11.0; 95% confidence interval [CI], 7.0–17.4). Near work such as close reading distance (<30 cm) and continuous reading (>30 minutes) independently increased the odds of having myopia in this sample of children.

Conclusions. Although myopia was not significantly associated with time spent in near work after adjustment for other factors, there were significant independent associations with close reading distance and continuous reading. These associations may indicate that the intensity rather than the total duration of near work is an important factor. (*Invest Ophthalmol Vis Sci.* 2008;49:2903–2910) DOI:10.1167/iovs.07-0804

Because of the association of myopia with educational performance and close-work occupations,[1] near work has long been considered an environmental risk factor for the development of myopia.[2–4] Among the various pillars of supporting evidence that link myopia to education and near work are the higher myopia prevalence rates that paralleled the introduction of schooling in Eskimo populations,[5] the higher prevalence of myopia in orthodox Jewish boys who undertook intense schooling compared with that in orthodox girls or boys and girls in general schools,[6] and the presence of myopia among Chinese fishermen who reported reading in childhood.[7]

It was initially assumed that increased accommodation associated with near work mediated the effects of education on the development of myopia.[8] However, studies using detailed time-based or accommodation-weighted measures of near work have not demonstrated strong associations between near work and myopia, particularly when the influence of other factors such as parental refractive error are taken into consideration.[9,10] As an alternative explanation of the link between education and myopia, it has been proposed that the hyperopic defocus induced by accommodative lag during near work stimulates eye growth, since imposed hyperopic defocus is a powerful stimulus for eye growth in animal models.[11–13] Accommodative lag is higher in myopic than in emmetropic children,[14] but the critical question is whether greater accommodative lag is seen before the onset of myopia in those who subsequently progress to myopia. The evidence on this issue is controversial.[15,16]

Whether accommodation has any role has been called into question.[11] Attempts to reduce myopia's progression by reducing the need for accommodation or accommodative lag, by providing clear vision without accommodation over a range of viewing distances, have shown clinically insignificant effects at best, except in the case of the small group of children with reduced accommodation and near esophoria.[17,18] Experimental studies in animals suggest that most eye growth control processes can operate in the absence of accommodation[11,19] and the spatially differentiated effects on eye growth when partial diffusers or lenses are used[20,21] are not compatible with regulation by a global phenomenon such as accommodation.

Currently, plausible evidence of a role for accommodation comes from the effectiveness of atropine in blocking eye growth in humans[22,23] and in experimental animal models of myopia.[24] However, muscarinic agents block axial elongation in chickens by acting via nonaccommodative mechanisms,[25] with possible alternative sites of action including direct effects on the sclera[26,27] or at retinal sites.[28] It is possible that the mechanisms controlling eye growth are actually quite different in chickens and humans, but such a difference would be surprising given the similarities in eye growth control mechanisms observed in chickens and nonhuman primates.[11]

Given the consistent evidence of a link between education and myopia, and the inconsistent evidence for a role of accommodation and near work, we sought to evaluate associations of

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myopia with near work in a population-based sample of Australian school children, with particular attention to variables such as the duration and type of activity and reading habits.

METHODS

Details of the sampling and examination methods for this project have been published[29] and are briefly outlined herein. Secondary schools across the Sydney metropolitan region were stratified by socioeconomic status, and 21 secondary schools were randomly selected by using a cluster design, to provide a representative sample of public (government) and private/religious schools. In Sydney, public schools are categorized as either comprehensive or selective. Although entry into selective schools is merit-based, enrollment in comprehensive schools is usually based on the area of residence. All year 7 students (mostly aged 12 years, with some aged 13 years) in the schools selected were invited to participate.

Approval for the study was obtained from the University of Sydney Human Research Ethics Committee, the New South Wales Department of Education, and the Catholic Education Office. The study adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from at least one parent after they received an explanation of the nature of the study. Verbal assent was also obtained from all children before examination.

Overall, 2353 children attending year 7 in the chosen schools (75.0% response) had parental permission to participate. Of these, 14 children were not examined because of absence during the school visit. The mean age of participants was 12.7 years (range, 11.1–14.4 years); their ethnic origins were predominantly European Caucasian (64.5%) or East Asian (15.0%).

Examination

After amethocaine was instilled, cycloplegia was induced using cyclopentolate 1% (two separate drops). Autorefraction was performed around 25 to 30 minutes after the last drop (RK-F1 autorefractor; Canon, Tokyo, Japan). This method of examination was preferred over cycloplegic retinoscopy or noncycloplegic autorefraction because it has been shown to provide more reliable measurements in young children.[30,31] An optical biometer (IOLMaster; Carl Zeiss-Meditec, Oberkochen, Germany) was used to measure axial length, corneal radius of curvature, and anterior chamber depth. Axial length was measured as the distance from the anterior corneal vertex to the retinal pigment epithelium along the fixation line. The validity of each axial length measurement was assessed by using signal-to-noise ratio (SNR), with SNR $\geq$2.0 indicating a reliable result. The average of five valid axial length measurements was used in the analysis. The corneal radius of curvature was measured along the flattest and steepest meridians. Three consistent keratometry measurements (each of which was the result of five measurements) were used in the analysis. Keratometry measurements were accepted as consistent if corneal astigmatism did not vary by more than 0.10 D between readings, and the astigmatic axis varied by 5° or less for astigmatism of at least 0.50 D and 10° or less for astigmatism of less than 0.50 D.

Questionnaire Data

Participating children completed a 65-item questionnaire that included information about near-work factors, such as the amount of time spent in near work and outdoor activities and the duration of continuous reading (questionnaire available at http://www.cvr.org.au/sms.htm). Near-work activities included completing homework, reading for pleasure, playing musical instruments, using a computer, playing hand-held console games, and playing video games and board games. Watching television, videos, or digital video discs (DVDs) was classified as a midrange activity and was not included as near work. The total number of hours spent in near work per day was assessed for weekdays and weekends separately and was used to calculate the total time spent in near work each week. To assess the duration of continuous reading, children were asked about the time they spent in continuous reading or close work before taking a break of 5 minutes or longer. Outdoor activities included general activities (such as being in one's own backyard, walking, or riding a bike or scooter), leisure activities (such as a barbeque, a picnic, spending time at the beach, or going for bush walks), and outdoor sport.

Parents completed a 173-item questionnaire, which collected sociodemographic data including ethnicity, level of education and occupation. Details of their child's medical history and any developmental delay—for example, in achieving developmental milestones, or learning difficulties—were also ascertained. The questionnaire asked parents whether they thought their children held books close to the face during near-work activities, and if so, to estimate the working distance as 0 to <10 cm (0 to <4 in.), 10 to <20 cm (4 to <8 in.), 20 to <30 cm (8 to <12 in.), or unsure. Duplicate questions about the time children spent in near work and outdoor activities were included in the parents' questionnaire, for corroboration of the students' answers. To determine whether the parents had myopia, we asked whether they needed to use spectacles or contact lenses, the age at which they first used them, and the reason for using spectacles (for distance viewing only or near work only or for both distance viewing and near work). Spectacle prescriptions were obtained from parents or their prescribers when possible. If the prescriptions were not available, spectacle-use questions were used to decide whether the parents were myopic or nonmyopic.[32] Between 48% and 50% of parents in the study who answered the spectacle-use questions reported not using spectacles. Of all parents who were identified as myopic (436 mothers and 355 fathers), most (73.6% of mothers and 76.9% of fathers) were determined by the questionnaire data alone. Myopic prescriptions confirming questionnaire data were available for 26% and 23% of the mothers and fathers, respectively.

Definitions

Myopia was defined as spherical equivalent refraction (SER, sphere +½ cylinder) −0.50 D or less. Children without anisometropia (defined as ≥1.00 D) and with SER ≤ −0.50 D in either eye were classified in the myopic group. Children with anisometropia were categorized based on the more ametropic eye. Parental ethnicity was classified on the basis of self-identification, and in the child if both parents shared that ethnic origin, using ethnic categories largely consistent with those defined by the Australian Standard Classification of Cultural and Ethnic groups (available at http://www.abs.gov.au, document 1249.0). The ethnicity categories in the present study were European Caucasian, East Asian, Indian/Pakistani/Sri Lankan (South Asian), Middle Eastern, South American, Melanesian/Polynesian, Indigenous Australian, African, mixed, and other. Time spent in near work and outdoor activities was analyzed as hours per week, determined from the students' completed questionnaires. Correlations (r) between students' and parents' estimates of time spent in individual near-work activities ranged between 0.5 and 0.6 (all $P < 0.0001$). Reading distances were parents' estimates based on observation of their children. The accommodation-weighted near work variable diopter-hours proposed by Mutti et al.[10] was calculated for our sample by using a modification of the original definition, as follows: total diopter hours per week = (three times homework) + (three times reading) + (three times hand held games) + (two times playing musical instruments) + (two times using a computer) + (two times playing video games) + (two times playing board games). Using the time spent per week in these near-work and outdoor activities, a near-work/outdoor activity ratio was also calculated.

Data Analyses

Data were analyzed by commercial software (SAS software, ver. 9.1.3; SAS Institute, Cary, NC). Mixed models and generalized estimating equations examined associations and subgroup differences, adjusting for the effects of cluster-sampling. Pair-wise statistical interactions between near-work parameters and other risk factors for myopia were assessed in general linear models. The R^2 values of multivariate models for spherical equivalent refraction (linear model) and myopia (logistic

regression model) were evaluated for the contribution of explanatory variables. The t and χ^2 tests were used when cluster effects were not significant. All confidence intervals (CI) are 95%.

Results

Sample Characteristics

Most (83.8%, $n = 1971$) of the 2353 children in this sample attended public schools; whereas 382 (16.2%) were from private schools. Response rates for public and private schools were 75.4% and 80.8%, respectively. Sex and ethnic differences between the public and private school samples were statistically significant (both $P < 0.0001$), with a higher proportion of boys (64.1% vs. 47.0%) and a higher prevalence of European Caucasian ethnicity (81.3% vs. 55.8%) in the private school sample than in the public school sample. The mean ages of the children in public schools and in private schools were 12.7 and 12.8 years, respectively ($P < 0.0001$).

Demographic characteristics of participants and nonparticipants in the study were fairly similar, with boys comprising 50.0% and 51.6%, respectively; and European Caucasian ethnicity 60.0% and 67.8%. Of the participants and nonparticipants, 83.8% and 82.8% attended public schools, respectively.

The children in the public selective school sample had the highest rate of myopia (41.6%) compared with that in the private (10.7%) or public comprehensive (9.4%) schools sample. The odds ratio was also highest (OR, 3.8; CI, 2.7–5.4), after adjustment for age, sex, and ethnicity. We previously reported on the higher proportion of myopia found in girls than in boys (14.1% vs. 9.7%) and in children of East Asian ethnicity than in those of European Caucasian ethnicity (39.5% vs. 4.6%).[33]

Sex, Ethnicity, and School Differences

Overall, the average number of hours spent in near work during a school week in this sample of 12-year-olds was 27.4 hours (CI, 26.8–28.0 hours). Doing homework (mean, 7.6 h/wk) and using a computer (mean, 6.4 h/wk) were major near-work components, although sex-, ethnicity- and school-related differences in near work and outdoor activity patterns were evident (Table 1). The girls reported spending significantly more time than did the boys in the near-work activities of completing homework, reading books and using a computer. Less total near work was reported by the children of European Caucasian ethnicity than by those of East Asian ethnicity and by those attending public comprehensive schools than by those attending other school types (Table 1).

Near Work, Refraction, and Ocular Biometry

Of all near-work activities, only the time spent reading for pleasure was independently associated with SER after adjustment for age, sex, ethnicity, and school type ($P_{trend} = 0.02$, Table 2). In general, there was only a very weak correlation between SER and hours spent in near-work activities (correlation coefficient for all, $r \leq -0.2$; Table 3). Time spent in near-work activities also correlated poorly with axial length and corneal curvature (all $r < 0.09$; Table 3).

As expected, the children who spent more time reading for pleasure reported longer periods of continuous reading ($\chi^2 < 0.001$). There was no association, however, between time spent in reading for pleasure and reading distance ($\chi^2 = 0.2$), or between continuous reading time and reading distance ($\chi^2 = 0.4$). Parental reports of close reading distance (<30 cm) were significantly associated with less hyperopic refraction (0.11 D vs. 0.42 D, $P = 0.0001$) after adjustment for age, sex, ethnicity, and school type. Similar adjusted analyses showed that with parental reports of close reading distance (yes or no), mean axial lengths were 23.47 and 23.38 mm, respectively ($P = 0.08$), while mean corneal curvature were 7.76 and 7.78 mm ($P = 0.3$). Children who reported reading continuously for longer periods tended toward myopia, although the tendency did not reach statistical significance after adjustment ($P_{trend} = 0.06$, Table 4) and was not associated with axial length ($P_{trend} = 0.3$) or corneal curvature ($P_{trend} = 0.08$).

Spending greater time outdoors was associated with slightly more hyperopic refractions (β coefficient 0.03, $P < 0.0001$), and correlated weakly with total time in near-work activities, and with diopter hours (both $r = 0.1$, $P < 0.0001$). A higher ratio of near work hours to outdoor hours ($P_{trend} = 0.001$), but

Table 1. Time in Near-Work Activities: A Comparison of Mean Hours per Week (CI)

	n	Completing Homework	Reading Books for Pleasure	Using a Computer	Playing Console Games	Combined Near-Work Activities*	Combined Outdoor Activities†
Whole sample	2353	7.6 (7.5–7.8)	4.5 (4.3–4.7)	6.4 (6.2–6.6)	3.7 (3.5–3.9)	27.4 (26.8–28.0)	12.3 (11.9–12.6)
Sex							
Girls	1163	8.4 (8.1–8.6)‡	4.9 (4.7–5.2)‡	6.5 (6.2–6.8)‡	2.1 (1.9–2.3)‡	26.4 (25.6–27.2)‡	11.6 (11.2–12.1)‡
Boys	1190	6.9 (6.7–7.2)	4.0 (3.8–4.3)	6.2 (5.9–6.5)	5.4 (5.0–5.7)	28.3 (27.5–29.2)	12.9 (12.4–13.3)
Ethnicity							
European Caucasian	1406	7.3 (7.1–7.5)§	4.1 (3.9–4.4)§	6.1 (5.8–6.3)§	3.7 (3.5–4.0)	26.0 (25.3–26.7)§	13.5 (13.1–13.9)§
East Asian	352	9.1 (8.6–9.6)	5.9 (5.4–6.4)	8.0 (7.4–8.6)	3.1 (2.6–3.5)	32.5 (31.0–34.1)	8.5 (7.8–9.2)
School							
Comprehensive public school‖	1734	7.1 (6.9–7.4)#	4.1 (3.9–4.3)#	6.5 (6.3–6.8)#	4.2 (3.9–4.4)#	27.2 (26.4–27.9)#	12.8 (12.4–13.2)#
Selective public school¶	237	9.0 (8.4–9.5)	7.0 (6.3–7.6)	6.8 (6.1–7.4)	2.4 (2.0–2.9)	31.1 (29.5–32.6)	9.0 (8.2–9.8)
Private school	382	9.1 (8.7–9.5)	4.6 (4.1–5.1)	5.5 (5.0–5.9)	2.6 (2.2–2.9)	26.0 (24.8–27.1)	11.9 (11.2–12.6)

Stratification by sex, ethnicity (European Caucasian vs. East Asian) and school (comprehensive, selective, and private) is shown.

* Includes completing homework, reading, playing musical instruments, using a computer, and playing hand-held console games, video games, and board games. Parent responses for time their children spent in combined near-work activities was 26.9 h/wk.

† Outdoor activities include time spent outdoors and in leisure activities. Parent responses for time their children spent outdoors was 11.8 h/wk.

‡ Kruskal-Wallis test <0.01, for differences between boys and girls.

§ Kruskal-Wallis test <0.0001, for differences between European Caucasian and East Asian ethnic groups. The sample sizes of other ethnic groups (Middle Eastern, South Asian, Oceanian, African, Indigenous, and South American) were too small for meaningful subgroup analyses and therefore not included in ethnic comparisons.

‖ Government schools with no entry criteria.

¶ Government schools with entrance examination.

Kruskal-Wallis test <0.01 for differences between the three school types.

TABLE 2. Mean SER (CI) and Time in Near-Work Activities among 12-Year-Old Children

Near-Work Activity (h/wk)	Crude Mean SER	Mean SER, Adjusted for Age, Sex, Ethnicity, and School
School homework		
None	0.73 (0.38–1.09)	0.43 (0.10–0.75)
<6	0.51 (0.41–0.62)	0.39 (0.29–0.48)
6–10	0.32 (0.24–0.40)	0.35 (0.28–0.43)
11–15	0.19 (−0.10–0.47)	0.37 (0.12–0.63)
>15	0.11 (−0.06–0.27)	0.28 (0.14–0.43)
P	<0.0001	0.8
R^2	0.01	0.2
Reading books for pleasure		
None	0.62 (0.50–0.75)	0.43 (0.31–0.54)
<6	0.42 (0.34–0.50)	0.40 (0.33–0.47)
6–10	0.00 (−0.13–0.14)	0.17 (0.05–0.29)
11–15	0.01 (−0.26–0.28)	0.22 (−0.02–0.46)
>15	0.15 (−0.09–0.39)	0.31 (0.10–0.54)
P	<0.0001	0.01
R^2	0.02	0.2
Computer use		
None	0.56 (0.35–0.77)	0.52 (0.33–0.71)
<6	0.38 (0.30–0.47)	0.33 (0.25–0.40)
6–10	0.34 (0.22–0.45)	0.37 (0.27–0.47)
11–15	0.30 (0.10–0.49)	0.33 (0.15–0.50)
>15	0.20 (0.03–0.38)	0.36 (0.20–0.52)
P	0.1	0.5
R^2	0.003	0.2
Playing hand-held console games		
None	0.11 (0.00–0.22)	0.32 (0.26–0.39)
<6	0.43 (0.34–0.51)	0.40 (0.30–0.50)
6–10	0.49 (0.33–0.66)	0.45 (0.20–0.71)
11–15	0.55 (0.30–0.80)	0.30 (−0.13–0.74)
>15	0.55 (0.31–0.79)	0.52 (0.12–0.92)
P	0.1	0.6
R^2	0.01	0.2
Combined near-work activities*		
<15	0.52 (0.38–0.66)	0.37 (0.24–0.49)
16–30	0.41 (0.33–0.50)	0.35 (0.28–0.43)
31–45	0.13 (0.02–0.25)	0.31 (0.20–0.41)
>45	0.36 (0.18–0.55)	0.46 (0.30–0.63)
P	0.01	0.5
R^2	0.01	0.2

* Includes completing homework, reading, playing musical instruments, using a computer, and playing hand-held console games, video games, and board games.

not to diopter hours of near work (P_{trend} = 0.2), was significantly associated with more myopic refraction in multivariate analyses.

Multivariate Analyses of Myopia

In the final multivariate model, significant associations with myopia were ethnicity, school type, parental myopia, continuous reading for 30 minutes or longer (31–45, 46–60, and >60 minutes) and close reading distance of less than 30 cm (Table 5). The multivariate adjusted OR for myopia in the East Asian children, compared with the European Caucasian children was 11.0 (CI, 7.0–17.4), and in the children with at least one myopic parent was 2.7 (CI, 1.9–3.8), compared with those with none. The children attending selective schools were twice as likely to have myopia in this final model as were those in comprehensive schools (OR, 2.2; CI, 1.4–3.4). The association of height with refraction, previously hypothesized,[34] but not consistently reported,[35,36] was also evaluated in multivar-

TABLE 3. Correlation (*r*) of the Time Spent in Near-Work Activities with Axial Length and Corneal Radius

	SER		Axial Length		Corneal Radius	
Near-Work Activity (h/wk)	*r*	*P*	*r*	*P*	*r*	*P*
School homework	−0.09	<0.0001	0.02	0.3	−0.008	0.7
Reading books for pleasure	−0.2	<0.0001	0.06	0.005	−0.04	0.1
Computer use	−0.07	0.0009	0.03	0.2	−0.005	0.8
Playing hand-held console games	0.01	0.5	0.05	0.01	0.07	0.002
Combined near-work activities*	−0.1	<0.0001	0.09	<0.0001	0.03	0.2

* Includes completing homework, reading, playing musical instruments, using a computer, and playing hand-held console games, video games, and board games.

TABLE 4. Associations of Near-Work Parameters with SER in 12-Year-Old Children

Near-Work Factor	Mean SER (CI)	
	Unadjusted	Adjusted for Age, Sex, Ethnicity, and School Type
Close reading distance*		
Yes (<30 cm)	−0.10 (−0.27–0.06)	0.11 (−0.03–0.26)
No (≥30 cm)	0.46 (0.40–0.53)	0.42 (0.36–0.48)
P	<0.001	0.0003
Continuous reading (minutes)†		
<16	0.58 (0.48–0.69)	0.46 (0.36–0.56)
16–30	0.40 (0.31–0.49)	0.40 (0.32–0.48)
31–45	0.31 (0.19–0.43)	0.37 (0.26–0.48)
46–60	0.19 (0.02–0.36)	0.27 (0.12–0.42)
>60	0.08 (−0.09–0.26)	0.20 (0.05–0.36)
P	<0.0001	0.06
Use of desk light for reading		
Yes	0.27 (0.18–0.36)	0.34 (0.26–0.42)
No	0.42 (0.32–0.51)	0.39 (0.32–0.45)
P	0.02	0.4
Diopter hours‡		
1st quintile (lowest)	0.53 (0.40–0.66)	0.39 (0.27–0.50)
2nd quintile	0.53 (0.41–0.66)	0.42 (0.30–0.53)
3rd quintile	0.33 (0.21–0.46)	0.32 (0.20–0.43)
4th quintile	0.28 (0.16–0.41)	0.35 (0.24–0.47)
5th quintile (highest)	0.10 (−0.03–0.23)	0.30 (0.19–0.42)
P	<0.0001	0.6
Near-work/outdoor activity ratio§		
1st quintile (lowest)	0.71 (0.58–0.83)	0.46 (0.35–0.58)
2nd quintile	0.53 (0.40–0.65)	0.40 (0.28–0.51)
3rd quintile	0.42 (0.30–0.55)	0.34 (0.23–0.46)
4th quintile	0.28 (0.15–0.40)	0.38 (0.27–0.50)
5th quintile (highest)	−0.15 (−0.28–−0.03)	0.19 (0.07–0.30)
P	<0.0001	0.02

* Reported by parents.

† Defined as time spent in continuous reading before taking a break of 5 minutes or longer on any given day.

‡ Total diopter hours = three times (hours spent in homework + reading + hand-held games) + two times (hours spent in playing musical instruments + using a computer + playing video games + playing board games). Range of diopter hours for quintiles are 0–41.5 (1st quintile), 42.0–55.5 (2nd quintile), 56.0–70.5 (3rd quintile), 71.0–92.5 (4th quintile), and 93.0–256.0 (5th quintile).

§ Calculated based on hours spent in near-work and outdoor activities per week. Near-work activities include completing homework, reading for pleasure, playing musical instruments, using a computer, and playing hand-held console games, video games, and board games. Outdoor activities include time spent outdoors and in leisure activities. Mean near-work/outdoor activity ratios for quintiles are 0.5 (1st quintile), 1.1 (2nd quintile), 1.6 (3rd quintile), 2.7 (4th quintile), and 13.7 (5th quintile).

iate analyses (Table 5). In the children in this sample, there were no statistically significant associations with myopia, and excluding height from our final multivariate model had no discernible impact on the magnitude of association from other variables.

The final multivariate model explained approximately one third of the variability in myopia and SER (34% and 29%, respectively). Excluding factors from this final model showed that the contribution of ethnicity was greater than that of age, sex, height, near work parameters, and outdoor activity combined (Table 6).

In the European Caucasian children alone (complete data were available for 1018 children), myopia was associated with reading distances less than 30 cm ($P = 0.04$), but not with continuous reading for 30 minutes or longer ($P = 0.08$), in multivariate analyses. For the 238 East Asian children with complete data, these two near work parameters were not significantly associated with myopia ($P > 0.2$).

Near Work, Outdoor Activity, and Parental Myopia

The time spent in individual near-work tasks was not associated with myopia in the whole sample, and in crude models it accounted for less than 2% of the variability in SER. Overall, time spent outdoors (hours per week) was associated with very little difference in SER (+0.01 D increase in SER) after adjustment for age, sex, ethnicity, school type, parental myopia, and near-work parameters.

In the children with two myopic parents, whose parents reported close reading distances, the mean SER was −2.58 D, whereas in the children without myopic parents and no reported close reading distance, the mean SER was +0.65 D (Table 7). There was a significant interaction of parental myopia and close reading distance ($P < 0.0001$) for SER, however, when this was tested in the final multivariate model for myopia, this interaction term was not statistically significant ($P = 0.8$).

Interaction effects from close reading distance and less time spent outdoors were significant for increasing myopic refraction ($P < 0.0001$), as were interaction effects from continuous reading and less time spent outdoors ($P < 0.0001$).

DISCUSSION

In this epidemiologic study of refractive error and near-work activity in 12-year-old Australian school children, time spent in

TABLE 5. Demographic Factors and Near-Work Parameters in the Final Multivariate Model for Myopia in 12-Year-Old Children

	Multivariate-Adjusted OR (CI)	*P*
Age	1.4 (0.9–2.1)	0.1
Sex (girls vs. boys)	1.4 (0.99–2.02)	0.06
Height	1.02 (0.99–1.04)	0.2
Ethnicity		
European Caucasian	Reference	Reference
East Asian	11.0 (7.0–17.4)	<0.0001
School type		
Comprehensive	Reference	Reference
Selective	2.2 (1.4–3.4)	0.001
Private/religious	1.7 (1.02–2.7)	0.04
Parental myopia		
No parental myopia	Reference	Reference
Myopia in at least one parent	2.7 (1.9–3.8)	<0.0001
Highest parental education		
TAFE or lower	Reference	Reference
University or higher	1.3 (0.9–1.8)	0.3
Continuous reading >30 minutes*	1.5 (1.05–2.1)	0.02
Close reading distance (<30 cm)	2.5 (1.7–4.0)	<0.0001
Outdoor activity (hours per week)†	0.97 (0.94–0.995)	0.02

TAFE, Technical and Further Education institution which provides trade skills–based training.

* Defined as time spent in continuous reading before taking a break of at least 5 minutes on any given day.

† General outdoor activities, leisure activities, and outdoor sports.

continuous reading (>30 minutes) and parental reports of close reading distance (<30cm) were associated with greater odds of myopia (OR, 1.5 and 2.5, respectively) after adjustment for age, sex, ethnicity, school type, parental myopia, and outdoor activity.

Time in Near Work and Myopia

Near work is often reported as an established environmental risk factor in childhood myopia,[37–40] although detailed studies of near work in which time-based measures were used, or with adjustments for other contributing factors, have provided only weak evidence to support this hypothesis.[9,10,41] In school-based samples of younger children in Singapore, only books read per week was an independent risk factor for higher levels of myopia.[9]

In the present study, near-work activity was determined in a school-based sample of children aged ~12 years. Although there was a tendency toward greater myopic refraction with greater time spent in near-work activities, only the duration of reading books for pleasure was independently associated with myopia, after adjustment for the influences of age, sex, ethnicity, and school type. When other relevant factors such as parental myopia and near work parameters were controlled for, however, the time spent in reading books for pleasure became nonsignificant. Although playing hand-held console games was associated with a more hyperopic refraction in crude analyses ($P_{trend} < 0.0001$), common sense suggests that this activity per se is unlikely to have a protective influence on the development of myopia. In this sample, we found only weak correlations between time spent playing console games with doing homework ($r = -0.06$, $P = 0.009$) or reading for pleasure ($r = -0.02$, $P = 0.4$), suggesting that the apparent protective effects may not be mediated by a substitution effect.

Time spent outdoors has been reported to confer small but significant protective effects against myopia.[10,42] In addition to total time spent in outdoor activity, the relative proportions of near work and outdoor activity also appear to be relevant for SER. The magnitude of the effect on SER from continuous reading (greater than 30 minutes) and time spent outdoors appeared similar when assessed in multivariate models (β coefficients −0.07 [D/duration of continuous reading in minutes] and 0.01 [D/hours spent outdoors], respectively).

Near Work Behaviors and Myopia

Given the relatively weak associations between near work and myopia reported in the literature, it has been suggested that the behavioral aspects of reading may be more important.[11] There is considerable speculation about how near work may induce differential hyperopic defocus in susceptible individuals, including whether accommodative lag or the balance between accommodative convergence and accommodation is important and variable.[15,16,43]

TABLE 6. Explanatory Variables and Their Contribution to SER (R^2)* and Odds of Myopia (Max Rescaled R^2)†

	Final Model‡	Final Model Excluding Ethnicity	Final Model Excluding School Type	Final Model Excluding Parental Myopia	Model Including Only Ethnicity, School Type, and Parental Myopia
SER (%)	29	18	28	24	25
Myopia (%)	34	23	33	31	29

* R^2 of final linear model for spherical equivalent refraction.

† Max-rescaled R^2 of final logistic regression model for myopia.

‡ Includes age, sex, height, ethnicity, school type, parental myopia, parental education, outdoor activity, continuous reading, and close near-work distance.

TABLE 7. Mean SER (SD) in Children with Parental Myopia and Reported Close Reading Distances

	No Parental Myopia	One Myopic Parent*	Two Myopic Parents†	P_{trend}
Reading distance <30 cm	0.58 (1.22)	−0.49 (2.45)	−2.58 (2.76)	<0.0001
Reading distance ≥30 cm	0.65 (0.97)	0.38 (1.00)	−0.43 (1.86)	<0.0001

* $P = 0.003$ for difference between reading distance <30 and ≥30 cm.
† $P = 0.002$ for difference between reading distance <30 and ≥30 cm.

Our study confirmed only weak correlations between hours of near-work activity and SER, but found significant association with close reading distance, an observation that has also been reported in teenage students in Singapore.[44] Continuous reading (>30 minutes) was a significant factor for myopia in this sample after adjustment. Interpreted in the context of current theories of myopia, a close reading distance may provide a source of hyperopic defocus to the eye and, in conjunction with accommodative responses in susceptible individuals, could promote eye growth that is analogous to that found in animal models.[11] In addition, the significant finding for continuous reading may be related to the observation that the duration and frequency of interruptions to negative lens wear is important for myopia induction in animals.

Ethnic Differences in Near Work

The higher prevalence of myopia reported in some East Asian samples has often been attributed to the more intense schooling undertaken by these populations. In general, different measures of near work (parent-reported versus self-reported, types of activities included in near-work measures, and in-school versus out-of-school near work) and potential confounding environmental factors are some of the limitations in attempting to compare data from studies of the effects of near work in childhood myopia. In Singaporean Chinese school children, for example, approximately 19 hours is spent reading each week.[38] In the present study, the children reported spending less time reading for pleasure (4.5 h/wk), while in samples of predominantly European Caucasian children in the United States, time spent reading outside of school averages 4.4 hours per week.[10]

In the present study, we made attempts to limit some of these potentially confounding factors by examining near-work activities in two ethnically distinct groups of children drawn from an age-specific population-based sample. The children of East Asian ethnicity reported spending longer periods in near work than did the children of European Caucasian ethnicity, although in practical terms, the mean difference per day was relatively minor (<1 hour). Since the main contributors to this near work difference were homework and computer use, it probably reflects the higher proportion attending selective public schools and participating in after-school tutorial lessons among the East Asian ethnic group.

The similarities in near-work patterns for these two ethnic groups contrast with the marked differences in myopia prevalence within this sample (4.6% vs. 39.5%, European Caucasian vs. East Asian).[33] As indicated by the multivariate analyses, ethnicity appears to be a strong marker of risk for childhood myopia and appears to be independent of the time spent in near-work activity. The more hyperopic refraction in the European Caucasian children may act as a buffer against myopization. In addition, the higher levels of outdoor activity reported in this ethnic group may be protective.[10,42]

Strengths and Limitations

A potential weakness of this study is that near work was self-reported by the students, so that estimates of near work could be subject to recall bias. Other methods, such as the experience sampling method in which electronic beepers are used to prompt the completion of a self-reported survey throughout a given day,[45] have been shown to detect differences in near work between subgroups of participants. This method, however, would not be feasible in a large population-derived study such as ours. In other studies, research assistants have documented the number of hours students spend reading during school hours.[38] This form of assessment could be useful in future studies, to obtain more complete measures of total near work, since the current measures do not include time spent on near work during school hours. Another possible limitation is the use of subjective measures of reading distance (parent estimates) and duration of continuous reading (self-reported) in the present study. Such methods have been used in another previous study.[44] Although we acknowledge that the validity of these assessment methods can be subject to reporting bias or misclassifications, such as myopic parents reporting closer reading distances in their children or more diligent students overestimating periods of continuous reading, we performed multivariate analyses adjusting for parental myopia, ethnicity, and school type. More objective measures of near-work distance and continuous reading are clearly needed in future studies. To minimize other measurement errors in the study, we used standardized examination techniques and instruments with high reproducibility (autorefraction with the IOLMaster; Carl Zeiss Meditec).

Our inability to collect refraction data on nonparticipants is another limitation, since children with existing refractive errors would have been more likely to participate. This could have overestimated the strength of some reported associations. The similar demography of participants and the nonparticipants and relatively high participation rate provides some assurance that our study sample was likely to be fairly representative of Sydney school children, and that selection bias, if present, was likely to be only minimal.

Study Implications

The identification of close reading distance and continuous reading as possible risk factors for myopia in this study may have important public health significance. Given the widespread emphasis on reading and conscientious study habits in childhood, health promotion messages could encourage children to read with the book at a further distance, and to take breaks between periods of continuous reading. Whether these reading habits in children precede the development of myopia or whether they are a consequence of myopia are critical issues. As these findings are limited to only a few studies, we recommend that further exploration of the role of such modifiable risk factors be conducted in other populations.

CONCLUSIONS

Findings in this study of 12-year-old Australian children suggest that continuous reading and reported close reading distance are associated with myopia, even after adjustment for the effects of age, sex, ethnicity, school type, parental myopia, and

time spent in outdoor activities. Time in near-work activities, such as completing homework or using a computer, however, were not significantly associated with myopia, after adjustment for confounders.

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