Parental Myopia, Near Work, School Achievement, and Children's Refractive Error

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Purpose. To quantify the degree of association between juvenile myopia and parental myopia, near work, and school achievement.

Methods. Refractive error, parental refractive status, current level of near activities (assumed working distance-weighted hours per week spent studying, reading for pleasure, watching television, playing video games or working on the computer), hours per week spent playing sports, and level of school achievement (scores on the Iowa Tests of Basic Skills [ITBS]) were assessed in 366 eighth grade children who participated in the Orinda Longitudinal Study of Myopia in 1991 to 1996.

Results. Children with myopia were more likely to have parents with myopia; to spend significantly more time studying, more time reading, and less time playing sports; and to score higher on the ITBS Reading and Total Language subtests than emmetropic children (χ^2 and Wilcoxon rank-sum tests; $P < 0.024$). Multivariate logistic regression models showed no substantial confounding effects between parental myopia, near work, sports activity, and school achievement, suggesting that each factor has an independent association with myopia. The multivariate odds ratio (95% confidence interval) for two compared with no parents with myopia was 6.40 (2.17–18.87) and was 1.020 (1.008–1.032) for each diopter-hour per week of near work. Interactions between parental myopia and near work were not significant ($P = 0.67$), indicating no increase in the risk associated with near work with an increasing number of parents with myopia.

Conclusions. Heredity was the most important factor associated with juvenile myopia, with smaller independent contributions from more near work, higher school achievement, and less time in sports activity. There was no evidence that children inherit a myopigenic environment or a susceptibility to the effects of near work from their parents. (*Invest Ophthalmol Vis Sci.* 2002;43:3633–3640)

Of all the issues surrounding myopia in children, there is probably none so contentious yet crucial as understanding the relative contributions of environment—primarily near work—and heredity. Several clinical studies have documented an association between myopia and higher levels of children's near work.[1–4] Level of education is often used as a surrogate measure for near work with more myopia among the more educated.[5–10] Researchers in Asia point to their rigorous schooling system and the long hours children spend studying as being responsible for the high rates of myopia in Asia, rates that may be on the increase.[11–14] Support for an important role for near work also comes from animal studies that have demonstrated the plasticity of refractive error in response to environmental stimuli. Neonatal chicks, tree shrews, or monkeys experience increased ocular growth and become myopic or less hyperopic after wearing minus lenses, presumably to compensate for the hyperopic defocus produced by these lenses.[15–18] Hyperopic defocus from a deficient accommodative response in juvenile myopes is theorized to be the connection between near work in human myopia and the minus lens results from animal studies.[19] The current environmental model derived from these clinical and experimental studies is that exposure to hyperopic defocus from accommodative lag during prolonged near work leads to excessive growth of the eye and a myopic refractive error.

An equally strong case can be made for the view that refractive error is determined genetically. Parents who have myopia tend to have children with myopia. The prevalence of myopia in children with two parents with myopia is 30% to 40%, decreasing to 20% to 25% in children with one parent with myopia and to less than 10% in children with no parents with myopia.[20–22] An increasing number of parents with myopia significantly elevates the odds of being myopic, with an odds ratio of 5.09 reported for having two versus no parents with myopia.[23] Monozygotic twins tend to resemble each other in refractive error more than do dizygotic twins. Heritabilities for refractive error calculated from twin data are typically very high, on the order of 0.82 or greater.[24–26] Refractive error and the axial length of children's eyes are more closely related to parental refractive error than to children's near-work habits.[4] To date, genetic loci have been associated with pathologic myopia[27,28] but not with juvenile myopia.[29]

Two hypotheses may reconcile these divergent views. The first is a theory of inherited environment. The tendency for myopia to run in families may be due to a shared intense near-work environment within a family, rather than because of shared genes. Parents with myopia would pass on their own academic standards or love of reading to their children rather than passing on a myopic refractive error itself. The same argument would apply to twin data. Monozygotic twins may share a more similar environment, as well as identical genes, than do dizygotic twins, perhaps falsely inflating estimates of heritability.

Another theory that may reconcile genetic and environmental evidence is that there is a genetic susceptibility to the effects of environment. Both heredity and environment are important, but the trait inherited is sensitivity to the myopigenic effects of near work, rather than myopia itself. A child could perform intense near work but would not have myopia

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without the susceptibility genes. Another susceptible child who performs the same level of near work would have a higher risk of myopia. This theory has been suggested by several investigators[8,26,30,31] but rarely formally evaluated.[32] Modification of the risk of near work by parental history of myopia should be detectable as a statistical interaction, with near work having the strongest association with myopia when there are two parents with myopia and the weakest association when there are no parents with myopia.

Further complicating the task of unraveling the role of near work is the association between myopia and intellectual ability. Children with myopia tend to have higher intelligence test scores[10,33–38] and higher achievement test scores,[39] with better vocabularies and grades in school, than do nonmyopes.[40] It is conceivable that children with a special aptitude for schoolwork may be inclined to engage in more near work over a longer time. Perhaps a child's cognitive skills are more closely related to refractive error than is near-work behavior. This association also underscores the difficulty in using the highest level of education achieved as a surrogate for near work. Brighter children are more likely to do more near work[41] and to pursue higher education.

Untangling the relative importance of near work, heredity, and intellectual ability is impossible without assessing all three factors in the same subjects. To our knowledge, this analysis has not been performed in a previous study. The purpose of the present study is to evaluate the association between children's myopia and three important factors: parental myopia, children's visual activities, and children's performance on a standardized achievement test. In addition, the hypotheses of inherited environment and inherited susceptibility to the environment will be evaluated. A preliminary analysis of a subset of these data has been reported previously.[42]

Subjects and Methods

Subjects for this study were children in the eighth grade who participated in the Orinda Longitudinal Study of Myopia (OLSM), a community-based cohort study of risk factors for predicting the onset of juvenile myopia. Participants in OLSM included first through eighth graders, but the increase in the prevalence of myopia with age required restricting the age of participants.[43,44] Only data from eighth graders were used in this analysis to maximize the likelihood that any myopia that would occur had occurred, thereby minimizing participation by premyopes—children without myopia in whom it develops later. Parents gave consent for their child's participation after all study procedures were explained in accordance with the Declaration of Helsinki. Consent was obtained once for participation in OLSM and separately at a later date to obtain achievement test scores. The Orinda Union School District also gave permission to the investigators to obtain the achievement test scores of participating children. There were 394 of 467 eligible OLSM eighth grade participants in 1991 to 1996 whose parents consented to the release of their children's achievement test scores, a participation rate of 84%. Of these, four had incomplete OLSM examination data, and 24 had incomplete achievement test data, leaving 366 children for this analysis. The average age (±SD) of the sample was 13.7 ± 0.5 years. The sample was 45.5% female and predominantly white (89.1%), with smaller proportions of Asian-American (8.7%), Hispanic (1.9%), and African-American (0.3%) subjects. There was no difference in refractive error between participants and nonparticipants (*t*-test, $P = 0.0954$). The mean spherical equivalent for participants was -0.17 ± 1.56 D, and the mean for nonparticipants was -0.51 ± 1.85 D. There was, however, a difference between the two groups in the proportion of parents with myopia (χ^2 test, $P = 0.033$). Among the participants, 47% of the children had one parent with myopia, and 25% had two parents with myopia. In the group of children who did not participate, 38% had one parent with myopia and 20% had two parents with myopia.

Myopia was defined as at least −0.75 D and hyperopia as at least +1.00 D in each principal meridian on cycloplegic autorefraction. This definition was chosen to reduce the number of false-positive results for myopia, to exceed the 95% limits of agreement of the autorefractor,[45] to reach a level of myopia likely to produce clinical symptoms, and to maintain consistency with the definition used in previous reports of this project.[46] Children in the eighth grade in 1991 to 1996 who participated in this analysis enrolled in OLSM either as sixth graders in 1989 to 1991, as third graders in 1989 to 1991, or as first graders in 1989.

The variables in this analysis were children's refractive status (myopic, emmetropic, or hyperopic), the number of parents with myopia (none, one, or two), time spent in various activities, and standardized achievement test scores. Children's refractive error was measured each fall by autorefraction (R-1; Canon USA., Lake Success, NY, no longer manufactured) under tropicamide 1% cycloplegia. Tropicamide has been found to be an effective cycloplegic for the measurement of refractive error in this protocol.[47,48] The measurement protocol has been described in detail elsewhere.[49] Parents' refractive status was determined for each parent by a survey filled out by parents at study entry asking whether glasses were worn, for what purpose, and at what age they were first prescribed. Each parent was classified as myopic if he or she wore glasses only for distance viewing, or if glasses were worn for both distance and near, as long as the glasses were first prescribed before age 16 years. This method has been shown to classify myopia correctly with a sensitivity of 0.76 and a specificity of 0.74.[50] Children's near work was assessed each spring after OLSM testing by a survey completed by parents asking how many hours per week outside of school the child spent in five activities: (1) reading or studying for school assignments; (2) reading for pleasure; (3) watching television; (4) playing video/computer games or working on the computer at home; and (5) engaging in sports activities. These activities were analyzed separately and as a composite variable for near work weighted by the dioptric equivalent of an assumed working distance for activities 1 to 4. The purpose of this weighting was to quantify exposure to near work not just in terms of time, but also in terms of the accommodative effort required during each activity.[4] This diopter-hours (Dh) variable was defined as: Dh = 3 × (hours spent studying + hours spent reading for pleasure) + 2 × (hours spent playing video games or working on the computer at home) + 1 × (hours spent watching television).

The survey completed by parents when their children were in the eighth grade was used as the measure of the current level of near work in all analyses. Near-work activity during school was not quantified. Parents are not in a position to report on the details of near work while children are in school. The reliability of children as a source of near-work survey information has not been established, although agreement between parents' and children's near activities survey responses is rated as only fair.[51] We assumed that time spent in near work during school did not add substantially to the variability in near work for children of the same grade within the same school.

Achievement test scores were obtained from Form G of the Iowa Tests of Basic Skills (ITBS; Riverside Publishing Company, Chicago, IL), administered each spring by the Orinda Union School District, independently from the OLSM. The national percentile score from the test administered during each child's eighth grade academic year constituted the primary ITBS data used in this analysis. The local percentile scores, normed using students in the Orinda district alone, were available and also analyzed for a subset of 306 children in 1991 to 1995. The ITBS tests the mastery of skills important for school achievement in three areas: reading, language, and mathematics. Correlations between ITBS scores and those from IQ tests, such as the Wechsler Intelligence Scale for Children, are moderate, ranging from a low of 0.26 in third grade to high of 0.49 in fifth grade.[52] The three areas of the ITBS are intended to measure distinct skills,[53] but the intercorre-

TABLE 1. Hours Spent per Week in Various Activities Outside of School

Activity	All Subjects (n = 366)	Myopes (n = 67)	Emmetropes (n = 271)	Hyperopes (n = 28)
Studying	9.4 ± 5.7	11.2 ± 7.2*	8.9 ± 5.2	9.4 ± 4.9
Reading for pleasure	4.4 ± 4.5	5.8 ± 4.8†	4.1 ± 4.6	3.6 ± 2.9
Watching TV	8.3 ± 5.9	9.2 ± 6.8	8.3 ± 5.7	6.6 ± 4.5
Video games/computer	2.3 ± 3.3	2.7 ± 4.1	2.2 ± 3.2	1.4 ± 1.8
Diopter-hours	53.8 ± 26.8	65.1 ± 34.1†	51.5 ± 24.4	48.2 ± 21.2
Sports	9.3 ± 6.4	7.4 ± 6.7†	9.7 ± 6.2	9.8 ± 7.9

Wilcoxon rank-sum test comparing myopes or hyperopes with emmetropes. Wilcoxon testing was used because of the non-normal distribution of variables. None of the comparisons between emmetropes and hyperopes was significant. Comparisons between myopes and emmetropes were significant as marked. Data are expressed as mean hours ± SD.

* $P < 0.05$.

† $P < 0.005$

lations between sections are significant.[54] This may be because each section uses similar sets of cognitive skills or psycholinguistic abilities. Each ITBS section correlates with numerous sections of the Illinois Test of Psycholinguistic abilities, such as auditory vocal association and visual motor association.[52] Although there are three sections to the ITBS, factor analysis reveals that most of the variance in ITBS scores is accounted for by one variable, termed general scholastic ability,[53,55] which has been more specifically characterized as general reading ability.[54] The emphasis of the ITBS on reading ability make it particularly well suited for determining whether cognitive skills important for success in reading confound the relation between near work (primarily reading) and myopia in children.

RESULTS

Of the 366 children in the sample, 67 (18.3%) were myopes, 28 (7.7%) hyperopes, and 271 (74.0%) emmetropes (Table 1). The axial nature of the refractive errors can be seen by the correlation between axial length and spherical equivalent ($r = -0.48$, $P < 0.0001$). Survey results from parental report accounted for an average of 33.7 hours per week outside school (Table 1). On average, children spent nearly as much time studying as they did watching television or engaging in sports activities. Reading for pleasure occupied less than half the number of hours children spent studying. Children spent the least amount of time playing video games or working on a computer at home. The time spent in these visual activities varied as a function of refractive error. Consistent with previous reports, children with myopia spent more time engaged in near activities (1 to 4) and less time engaged in sports[36] (P = 0.0003), compared with emmetropes (Wilcoxon rank-sum test comparing myopes and emmetropes; Table 1). In particular, these near activities were studying for school assignments (P = 0.024) and reading for pleasure (P = 0.0019). As a result, the composite near-work variable of diopter-hours was also significantly greater for myopes than for emmetropes (P = 0.0015). Watching television and playing video games or working on the computer at home did not differ between myopes and emmetropes. Myopes also spent more time reading for pleasure (P = 0.034) and less time in sports (P = 0.049) and had a higher number of diopter-hours per week than hyperopes (P = 0.032; Wilcoxon rank-sum test comparing myopes and hyperopes). Emmetropes and hyperopes spent comparable amounts of time in all the various activities.

Study participants scored approximately 30 percentile points higher on average than the national norm and approximately 5 percentile points higher than the local norm in the three main areas tested by the ITBS (Table 2). Despite this good performance, variability was not severely compressed: One standard deviation in scores was roughly one-fifth to one-third of the entire possible range of scores. Again, consistent with previous reports,[10,33–35,37–40] myopes scored higher than emmetropes in both national and local percentile scores in the areas of Reading ($P < 0.013$) and Total Language ($P < 0.0069$; Wilcoxon rank-sum test comparing myopes and emmetropes; Table 2). Myopes also scored higher than hyperopes in national

TABLE 2. ITBS National and Local Percentile Scores

ITBS Subtest	All Subjects (n = 366)	Myopes (n = 67)	Emmetropes (n = 271)	Hyperopes (n = 28)
National				
Reading	79.6 ± 23.2	82.9 ± 23.7*	79.2 ± 23.1	75.3 ± 22.9
Total Language	82.8 ± 19.0	86.6 ± 17.7†	82.2 ± 19.2	79.0 ± 20.2
Mathematics	83.8 ± 19.8	84.1 ± 21.4	83.5 ± 20.0	86.3 ± 13.6
Local				
Number of test scores	306	58	229	19
Reading	53.7 ± 29.6	62.5 ± 31.0*	52.6 ± 28.9	41.5 ± 26.6
Total Language	55.1 ± 28.8	64.2 ± 29.7†	53.2 ± 28.1	52.2 ± 29.2
Mathematics	54.5 ± 28.5	57.4 ± 29.6	53.6 ± 28.4	59.7 ± 26.7

Wilcoxon rank-sum test comparing myopes or hyperopes with emmetropes. Wilcoxon testing was used because of the non-normal distribution of variables. None of the comparisons between emmetropes and hyperopes was significant. Comparisons between myopes and emmetropes were significant as marked. Data are expressed as the mean score ± SD.

* $P < 0.05$.

† $P < 0.01$.

Table 3. Proportion of Children with and Children without Myopia as a Function of Number of Parents with Myopia

Parental Myopia	Child with Myopia (n = 63)	Child without Myopia (n = 276)
None (n = 95)	6.3 (6)	93.7 (89)
One parent (n = 159)	18.2 (29)	81.8 (130)
Two parents (n = 85)	32.9 (28)	67.1 (57)

χ^2_2 = 21.0; P = 0.001; n = 339. Data are percentage of each parental myopia group, with the number of children in parentheses.

Reading (P = 0.011) and local Reading (P = 0.0095), in national Total Language (P = 0.018), but not local Total Language (P = 0.099; Wilcoxon rank-sum test comparing myopes and hyperopes). Hyperopes have been reported to score lower in reading achievement and IQ tests.[38,56,57] The lower scores for hyperopes compared with those of emmetropes in this study did not achieve statistical significance, perhaps because the number of hyperopes was small at this age, limiting statistical power. Mathematics achievement test scores were not different between any of the refractive groups. The higher scores for myopes in Reading and Total Language seem unlikely to be the result of greater visual comfort during testing. The similar scores in Mathematics suggest that each refractive group could see the test equally well, but that the groups may differ in skills specific for language.

Consistent with previous reports of associations between refractive errors in parents and children,[20–22] parents with myopia tended to have children with myopia (χ^2_2 = 21.0; P = 0.001; Table 3). This tended to follow a dose-dependent pattern. Of the children in families with two parents with myopia, 32.9% had myopia compared with 18.2% of the children in families in which only one parent was myopic and 6.3% of the children in families with no parents with myopia.

Table 4 shows the univariate odds ratios calculated to quantify the association between children's myopia and the factors identified as significant in Tables 1 through 3. Having either one (OR = 3.31; 95% confidence interval [CI] = 1.32–8.30) or two parents with myopia (OR = 7.29; 95% CI = 2.84–18.7) significantly increased the odds of being a myope, in a dose–response fashion. As suggested by the numeric values in Table 1, myopes tended to engage in more near work (OR = 1.018; 95% CI = 1.008–1.027) and to spend less time engaged in sports activities (OR = 0.936; 95% CI = 0.892–0.983). Myopia was significantly associated with local ITBS Reading (OR = 1.013; 95% CI = 1.003–1.024) and Total Language scores (OR = 1.014; 95% CI = 1.004–1.025), but not with national scores. This inconsistency, depending on the source of the score, suggests that the association between myopia and reading achievement as measured by the ITBS may be weak.

One of the difficulties in assessing these risk factors is their interconnection, and therefore their potential, for confounding the association with myopia. Perhaps myopes read more because they have better cognitive skills and therefore greater potential for achievement. Perhaps myopes score higher on school achievement tests because they study more. The most important potentially confounding association is between near work and parental refractive error. Perhaps parents with myopia have children with myopia only because they pass along a myopigenic environment with intense near-work demands. There were significant Spearman correlations between diopter-hours and all ITBS scores and between diopter-hours and hours of sports per week, indicating their potential for confounding the association between each of these factors and refractive error (Table 5). The number of diopter-hours did not differ significantly as a function of the number of parents with myopia (P = 0.31), indicating little potential for confounding, because parents with myopia did not appear to pass along a more intense near-work environment to their children.

Confounding was assessed in a multivariate logistic regression model (Table 4). The association between myopia and the number of parents with myopia, near work in diopter-hours per week, the number of hours spent in sports activities per week, and local ITBS Reading scores was adjusted for the effects of each other factor in this model. ITBS local Total Language was not significant in the multivariate model and was therefore excluded from the multivariate results in Table 4. Despite their correlations, the risk factors had very little confounding effect on the association with myopia—that is, univariate values were virtually unchanged when adjusted for the other factors in the multivariate model (Table 4). The odds ratio for having two compared with no parents with myopia decreased by only 12% when adjusted for near work, sports activities, and local ITBS Reading scores. Again, this suggests that the association between children's and parents' myopia may be due to heredity rather than to greater near-work demands being placed on children with myopia by parents with myopia. The odds ratio for near work did not change when adjusted for the number of parents with myopia, sports activity, and school achievement. Near work appears to have an independent association with myopia that is not explained by greater academic aptitude in myopes or myopia in parents. Similarly, myopes score higher in reading achievement independent of the greater amount of time they spend in near work.

Table 4. Univariate and Multivariate Odds Ratios and Confidence Intervals for the Association between Children's Myopia and the Various Risk Factors

Risk Factor	Univariate Odds Ratios	Multivariate Odds Ratios	P (Multivariate)
One myopic parent	3.31 (1.32–8.30)	3.32 (1.18–9.37)	0.023
Two myopic parents	7.29 (2.84–18.7)	6.40 (2.17–18.87)	0.0008
Diopter-hours per week	1.018 (1.008–1.027)	1.020 (1.008–1.032)	0.0013
Sports (h/wk)	0.936 (0.892–0.983)	0.917 (0.864–0.974)	0.0045
ITBS Reading local percentile score	1.013 (1.003–1.024)	1.014 (1.002–1.027)	0.0276
ITBS Total Language local percentile score	1.014 (1.004–1.025)	Not in multivariate model	NS

Data are odds ratios with confidence intervals in parentheses.
The multivariate model adjusts for all other factors listed.

Table 5. Spearman Correlations between Diopter-Hours and ITBS or Hours of Sports per Week

Variable	Correlation with Diopter-Hours	P
ITBS Reading (national)	0.231	<0.0001
ITBS Total Language (national)	0.242	<0.0001
ITBS Math (national)	0.192	<0.0001
ITBS Reading (local)	0.243	<0.0001
ITBS Total Language (local)	0.266	<0.0001
ITBS Math (local)	0.224	<0.0001
Sports (h/wk)	0.123	0.0210

The hypothesis of inherited susceptibility to near work can be evaluated statistically by testing whether there is significant interaction between near work and parental history of refractive error. We modeled this interaction with near work as a categorical and a continuous variable. Near work was dichotomized into high and low levels of near work split at the median level (50 Dh). Odds ratios associated with being in the higher compared with the lower level of near work were then calculated at each level of parental myopia history (none, one, or two parents with myopia). If the inherited susceptibility hypothesis is true, the odds ratio associated with near work should be the highest for two parents with myopia and the lowest for no parents with myopia. As seen in Table 6, the odds ratios were consistent across number of parents with myopia. When modeled as an interaction term in a logistic regression with near work as a continuous variable and parental myopia in three categories, there was also no evidence of statistically significant interaction ($P = 0.67$ for the interaction term, diopter-hours × number of parents with myopia).

Having found significant independent effects for parental history of myopia and near work, it would be useful to compare their relative impact. The total range of near work performed by children can be approximated by four standard deviations for diopter-hours, or roughly 100 Dh (4 × 26.8 Dh; Table 1). A child would have to increase the time spent in near work by more than half the total range of time in near work (61.3 Dh) to equal the effect of one myopic parent on the risk of myopia. Nearly the entire range of near work (94.7 Dh) equals the effect of two parents with myopia on the risk of myopia. Myopes and emmetropes differ by an average of only 13.6 Dh of near work (Table 1). This suggests that the smaller differences in near work that are likely to occur between children have less impact on refractive error than do hereditary influences.

Discussion

In this study, both heredity and near work were significantly associated with myopia, with heredity being the more important factor. We also found no evidence to support the theory that heredity is important only because parents with myopia have children who do more near work. Children of parents without myopia did as much near work as children of parents with myopia. This is consistent with previous studies that report on both near work and parental history of refractive error. Bear et al.[58] found little change in correlations between the refractive errors of family members after adjustment for the current level of near work, suggesting a strong genetic component independent of near work. Although Wong et al.[59] reported significant odds ratios for both hours per day of reading and familial tendency toward myopia, they did not assess the effect of each variable on the other by comparing univariate and multivariate odds ratios. In a sample of Singaporean conscripts with a highly myopic average refractive error of −6.1 D, Saw et al.[60] found that parental myopia was significantly related to myopia, but neither past nor current near work was a confounding variable, because near work was not associated with myopia. Parental myopia became nonsignificant when adjusted not for near work, but for educational level and placement in a program for the gifted in school.

Individual components of near work had different effects. The strongest associations between myopia and near-work activities were for studying and reading for pleasure (Table 1). In contrast to the concerns of parents, watching television, playing video games, or working on a computer at home were not associated with myopia. Having a television before the age of 12 for 1 to 3 years[59] and watching television from a close distance have been associated with myopia in Asia.[61] The risk did not behave in a dose–response fashion, however; having a television for longer periods was not associated with myopia.[59] The nearly universal exposure to television in the United States may make this a different variable than in Asia, where it may be more related to socioeconomic status. National prevalence estimates for myopia suggest that the impact of television is low. Adults who were born between 1917 and 1927 (presumed minimal exposure to television as children) had a prevalence of myopia as 45- to 54-year-old adults in 1971 to 1972 nearly identical with those who were born between 1947 and 1960 (12–17 years old in 1971 to 1972) with a greater exposure to television as children.[9] A decrease in the prevalence of myopia with age has been hypothesized to be due to increasing near-work demands in more recent decades. For example, prevalence estimates from the Framingham Offspring Eye Study show that 52% of adults aged 35 to 44 years are myopic, whereas only 20% of adults aged 65 to 74 years have myopia.[62] Our comparison of studies conducted nearly two decades apart argues against this assumption, indicating that this decrease in prevalence is due to age rather than increasing near-work demands placed on children with a more recent year of birth.[63]

Children with myopia also tended to engage in a lower amount of sports activity. This result could be due to a more introverted personality among myopes,[64,65] limitations to physical activities because of wearing glasses, or perhaps a true protective effect for sports activities. An impractical clinical trial randomizing children to various levels of sports activities would be needed to establish such an effect. The positive association between sports activity and diopter-hours in Table 5 is counterintuitive, considering that myopia is related to higher levels of near work and lower levels of sports activity. The correlation is driven by the positive correlation between diopter-hours and sports activity in nonmyopes (Spearman $r = 0.18$, $P = 0.002$), but not in myopes (Spearman $r = 0.016$, $P = 0.90$).

We also find no evidence that children inherit a susceptibility to the environment. In two previous studies, investigators have examined gene–environment interactions. Saw et al.[32] examined data for Singaporean children aged 7 to 9 years, finding that the proportion of children with more than −3.00

Table 6. Odds Ratios and Confidence Intervals for Myopia Associated with Performing 50 Dh or More of Near Work Compared with less than 50 Dh per Week

Parental Myopia	Odds Ratio for ≥50 Dh
None	2.09 (0.364–12.0)
One parent	2.22 (0.941–5.25)
Two parents	1.57 (0.60–4.09)

Data are odds ratios with 95% confidence intervals in parentheses.

D of myopia was higher if children read more than two books per week than if they read two or fewer books. This increase in myopia due to reading more books also varied by the number of parents with myopia. It is important to note, however, that this increase did not follow the dose–response pattern of the susceptibility hypothesis. The greatest increase associated with reading more than two books per week was with one parent with myopia (a factor of 4.46 times) with little difference between two and no parents with myopia (factors of 2.12 and 2.44 times, respectively). The interaction term in their model was significant, but the absence of a dose–response relation provides no clear support for an inherited susceptibility hypothesis.[32] Alternatively, near work and heredity may operate differently in Asian children than in the predominantly white sample in Orinda. Chen et al.[66] reported a study from Taiwan that showed a significant interaction between genes and environment, but the hereditary factor in that study was zygosity, not parental history of myopia. Therefore, that study sheds no light on the hypothesis of inherited susceptibility to near-work. However, their twin study offers some perspective on the relative importance of near work and heredity. They found that twins who are concordant in near-work habits are also concordant in refractive error more often than discordant twins, but by a greater amount if the twins are fraternal (by 24.2 percentage points) compared with identical (by 13.3 percentage points).[66] This may represent a ceiling effect, considering that the overall concordance rate in refractive error for identical twins was already high: 89.1% compared with 51.2% for fraternal twins. The relative effects of near work and heredity may be inferred by comparing the concordance rate among identical twins with similar near-work habits (92.4%) with the concordance rate for identical twins with discordant habits (79.1%). If the difference of 13.3 percentage points is the effect of environment and 79.1% is the effect of heredity, the ratio is 5.9:1.[66] Consistent with the present study, heredity may also be more important than near work in this sample of Asian twins.

Despite a long history of association with myopia, near work describes very little of the variance in refractive error compared with heredity. Models of refractive error with near-work variables generally have an R^2 between 2% and 12%.[1,2,4,7] This compares poorly with heritabilities of at least 0.82 in twin studies.[24–26] A limited role for near work is also supported by the modest effect of bifocal spectacles in children with myopia with esophoria at near. The progression of myopia is reduced by only 20% in children wearing bifocals compared with children wearing single-vision glasses.[67] The higher prevalence rates for myopia in Asia are consistently related to education[11,12,59,60] but have only been weakly associated with near work.[60,68,69] A recently reported significant odds ratio for near work in Chinese schoolchildren is difficult to interpret, because it is unclear whether it represents the effect of near work or an urban versus rural site.[70] Location may be an important confounding variable. After adjustment for location in a subsequent study, as well as for age, night-light use, and parental myopia, the only significant association between myopia and near work in a sample of Singaporean and Chinese children was for the number of books read per week, but not for hours of reading per day, a near-vision task index, additional classes, or computer use.[71] Similar to the present study, odds ratios for parental myopia were higher (3.44 for two compared with no parent with myopia) than for near work (1.43 for reading more than two compared with less than two books per week).[71] It may be that universal exposure to near work in Asian schooling makes it less important as a risk factor. As Saw et al.[60] have suggested, education may be a surrogate for intellectual ability rather than near work. Intellectual ability may be a more important risk factor than near work.[40,41] The impact of intellectual ability may be underestimated in the present study, because the OLSM sample was from a district where the average ITBS scores were above the national average and most students go to college. Alternatively, ITBS scores may be an imperfect marker for general intellectual ability, because they are only moderately correlated with IQ scores[52] and heavily emphasize skills important for reading.[53,54]

One limitation to the present study is that the survey used may be a crude estimate of the true near-work activity of children. Despite the greater detail of a survey conducted in Asia where near work has been presumed to play a greater role in myopia, the magnitudes of the association reported here and in Asia are similar. For example, if reading more than two books per week is taken to be a split at the median level of near work, the odds ratio of 1.43 in the Singapore-China study[71] compares well with our estimate of roughly 2.0 in Table 6. The issue of how much detail is needed and which detail is the most relevant has not been resolved. As stated earlier, books read per week seems to be the single critical feature of near work in studies in Asia.[69,71] Future research may benefit from measuring more specific components of near work and intelligence in a more detailed fashion in both parents and children to understand what is being transmitted genetically or environmentally and what role these factors play in myopia.[72]

A further limitation of this study is that results are cross-sectional rather than longitudinal, modeling the odds ratios associated with being a myope rather than with becoming a myope. Longitudinal follow-up analyses are needed to clarify the relative roles of near work and heredity in the onset of myopia. Our estimates of risk may also be affected by sampling at only one age. Although in most cases myopia initially occurs by the eighth grade,[43] some myopia has its onset in high school, college, and early adulthood. Our sample of emmetropes no doubt contains some future myopes. This may bias some of our estimates of risk toward the null.

We concluded from our cross-sectional data that both heredity and near work are associated with myopia, but that heredity is by far the more important factor. We also found no evidence to support two alternate theories, either that children with myopia resemble their parents because they do more near work or that they inherit a susceptibility to the environment.

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