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Myopia and intelligence: a pleiotropic relationship?

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Summary. The well-established association between myopia and superior intelligence in the general population was investigated in a group of intellectually gifted children and their less gifted full siblings to determine whether the relationship of myopia to psychometric intelligence is consistent with the hypothesis of pleiotropy, i.e., both characteristics are affected by the same gene or set of genes. Failure to find a difference in degree of myopia, assessed as a metric variable, between intellectually gifted and nongifted siblings would contradict pleiotropy. A variety of possible causal pathways, both genetic and environmental, have been hypothesized in the literature to explain the relationship between intelligence and myopia, and these still cannot be ruled out. It is theoretically noteworthy, however, in view of the independent evidence for the considerable heritability of both intelligence and myopia, that the highly significant gifted-nongifted sibling difference in myopia found in the present study is consistent with the hypothesis that intelligence and myopia are related pleiotropically.

Introduction

The purpose of the present study was to examine the hypothesis of a pleiotropic or other within-family relationship between mental ability and degree of myopia. Myopia was measured by the most advanced optometric instruments currently available in a sample of highly gifted youths and their intellectually somewhat less able, although generally well above average, full siblings. A finding that full siblings who differ in level of intelligence also differ in degree of myopia would be consistent with the hypothesis that the two traits are pleiotropic, that is, influenced by the same gene or genes. Because the expected degree of relationship between psychometric intelligence and myopia is not especially strong, it can be examined most efficiently by comparing extremely intelligent children with their less intelligent siblings. With an observed correlation of approximately 0.50 between the intelligence test scores of full siblings in the general population, one would expect the intelligence of the siblings of children who are selected for extremely high intelligence to fall, on average, about one-half of the way between the level of their gifted siblings and the mean of the population.

A positive relationship between myopia, or nearsightedness, and mental ability was first documented in a European population more than a century ago (Cohn 1883, 1886). Since then the positive correlation between myopia and various measures of intelligence and scholastic aptitude and achievement has been substantiated by numerous studies (Ashton 1985a; Baldwin 1981; Benbow 1986; Benbow and Benbow 1984; Douglas et al. 1967; Dunphy 1970; Grosvenor 1970; Heron and Zytoskee 1981; Hirsch 1959; Karlsson 1973, 1975; McManus and Mascie-Taylor 1983; Scholz 1970; Young 1963). The degree of relationship between myopia and mental ability in the general school population, as estimated in three large studies (Ashton 1985a; Hirsch 1959; Karlsson 1975), when expressed as a coefficient of correlation, is between about 0.20 and 0.25, which is equivalent to an IQ difference of about 6 to 8 points between myopes and nonmyopes. A study by Karlsson (1975), based on 2,527 California high school seniors, found a difference of 8 IQ points on the Lorge-Thorndike IQ test between pupils wearing correctional lenses for myopia ($N = 377$) and nonmyopes ($N = 2{,}150$). The largest and most recent study, by Rosner and Belkin (1987), based on a national sample of 157,748 Israeli Jewish males, aged 17–19 years, recruited for military service, found a strong positive association of myopia with measures of intelligence on both verbal and nonverbal tests and also with years of schooling independent of intelligence.

Early investigators attributed the cause of myopia and its relationship to mental ability to the excessive use of the eyes in reading and others forms of "nearwork" associated with schooling. With few exceptions (e.g., Bear et al. 1981; Richler and Bear 1980), however, the nearwork hypothesis has been rejected by modern investigators. Ashton (1985a) found no evidence that nearwork influences the development of myopia but confirmed the relationship between myopia and scholastic performance. However, other, as yet unidentified, environmental influences may affect the development of myopia, a point argued by Ashton (1985b), who suspects some unknown between-families nongenetic factors as the main source of population variance in myopia. Evidence of myopia in chicks due to experimentally induced visual deprivation suggests that the relative deprivation of nonfoveal retinal stimulation associated with foveal "nearwork," such as reading, may be a factor in the development of myopia in humans (Wallman et al. 1987).

For many years now, the general consensus among contemporary researchers on myopia has been that genetic factors are strongly involved (François 1961; Karlsson 1975; Waardenburg et al. 1963). Although the evidence for the inheritance of myopia is now substantial, the exact mechanism of inheritance of myopia is not yet firmly established. However, few geneticists, if any, still favor the hypothesis pro-

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posed by early investigators that myopia is a single-gene, or Mendelian, character. Two facts demand a polygenic model of the total variance in refractive error: (1) the refractive error underlying myopia is a continuous variable with a slightly skewed leptokurtic frequency distribution and (2) at least three separate but correlated optical factors involving the cornea, lens, and axial length of the eye from the cornea to the retina contribute to the refractive error that makes for myopia. The total range of refractive variation comprises myopia (nearsightedness), emmetropia (no refractive error), and hyperopia (farsightedness).

Also, a segregation analysis specifically aimed at testing the single-gene model found no support for it (Ashton 1985b). However, a number of studies of family pedigrees and studies based on monozygotic (MZ) and dizygotic (DZ) twins, siblings, and other kinships are impressively consistent with a model of polygenic inheritance involving both additive and nonadditive (recessive) effects (Furusho 1957; Jablonski 1922; Karlsson 1974, 1975, 1976; Sorsby et al. 1957, 1962, 1966; Sorsby and Fraser 1964; Wold 1949; Young 1958). Heritability analysis of the MZ and DZ twin data suggests that additive genetic effects account for almost 50% of the variance in ocular refraction, and additive plus nonadditive genetic factors account for most of the variance. There is no direct evidence that myopia is causally dependent on nearwork or reading or other scholastic activity. Moreover, the nearwork hypothesis seems to be contradicted by the fact that myopia occurs with comparable frequency in both literate and nonliterate populations (Post 1962) and is as frequent in persons with Down syndrome as in other persons from the same population (Lowe 1949).

All but one of the studies of the relation between myopia and intelligence are based on comparisons of the mean levels of intelligence, or IQ, of unrelated samples of myopes and nonmyopes in the general population. The relationship between myopia and indices of intelligence found in all such studies based on individuals from different families cannot serve the same theoretical purpose that would be served by the finding of a within-family (WF) relationship. As explicated elsewhere (Jensen 1980), the distinction between a population or between-family (BF) relationship and a WF relationship can be theoretically crucial for the interpretation of the correlation between physical and behavioral variables.

Why is it important to obtain both WF and BF correlations in interpreting correlations between traits, particularly between a physical and a mental trait? Jensen (1980) distinguishes between extrinsic and intrinsic correlation. A nonzero BF correlation, r_{xy}, when the WF $r_{xy} = 0$, is termed extrinsic; it implies no directly causal or functional relationship between traits x and y. The relationship between variables x and y, in this case, is due merely to population heterogeneity and is irrelevant to understanding the causal or functional connection between the traits in an individual. For example, various subpopulations differ quite markedly in the frequency of myopia and also happen to differ in average level of IQ. The Jewish and Oriental (Chinese and Japanese) populations show relatively high rates of myopia (Post 1962) and are also over-represented in school programs for the academically gifted and under-represented in classes for the educable mentally retarded (Benbow 1986; Terman 1925). Populations of African background, on the other hand, show the reverse pattern in school programs, as well as having a rate of myopia less than one-fourth that of the non-African population in the United States (Post 1962). In a heterogeneous population made up of these differing subpopulations, therefore, there will be a relation between myopia and IQ. But such a relation does not constitute evidence for any causal, function, or intrinsic relationship between myopia and IQ. That is to say, the two traits could be related only because of common assortment of the genes for the two traits, due to subpopulation differences in the two traits, or due to positive cross-assortative mating for the two traits. (The same logic also applies to any correlated environmental factors that may affect each trait.) Such an extrinsic relationship theoretically could be eliminated or reversed by genetic selection or by experimental manipulation of the environmental factors that influence the two traits.

A WF relation between different traits is said to be intrinsic in the sense that some common causal factor (or set of factors) is reflected in both traits. Genetically, this condition is known as pleiotropy, that is, the condition whereby a single gene or set of genes has two or more distinct phenotypic effects. A clear example of pleiotropy is seen in children afflicted by phenylketonuria (PKU), in which a single gene (a double recessive) causes both severe mental retardation and lightness of pigment relative to the unafflicted siblings. A WF correlation between two genetically determined traits usually implies pleiotropy. Pleiotropy need not produce a perfect WF correlation, however. If either one or both of the correlated traits were polygenic and the pleiotropic effect were due to only a single gene or some fraction of all the genes that condition the development of both traits, the pleiotropic correlation between the two traits would be less than perfect. Linkage, unless the genes are extremely close, is not likely to be an explanation because the linkage phase can be expected to vary from family to family.

Pleiotropy, of course, is not necessarily an exclusive cause of WF correlations. To the extent that the heritability of the correlated traits is less than 1, a WF correlation could be caused wholly or partly by within-family environmental correlations.

We have found in the literature only one study (Benbow 1986; see also Benbow and Benbow 1984) that specifically looked at the within-family relationship between myopia and ability. In a study of extremely precocious students (the 417 most academically giftes youths selected from over 100,000 gifted students identified in a talent search covering the entire United States), it was discovered that over 50% of the mathematically precocious and even more of the verbally precocious were myopic, while fewer than 5% were hyperopic, as compared with about 15%–20% of myopes in the general high school population. Myopia in the precocious group was determined by questionnaires mailed to their parents, who were also asked to report on the presence of myopia in any siblings of the precocious probands; 36% of the siblings were reported to be myopic, which is a significantly smaller percentage than the 53% of precocious probands who were reported to by myopic. Among the parents of the extremely precocious, 55% reported being myopic. The greater incidence of myopia in the parents than in their gifted children (55% vs 53%) is most likely attributable to the increase in myopia with age. Although the Benbows did not measure the IQs of the gifted probands' siblings or parents, it seems safe to infer from simple regression considerations that the IQs of the siblings and parents were lower, on average, than the IQs of the highly selected sample of gifted youngsters. Hence we would conclude that these data indicate a WF correlation between mental ability and myopia, granted that there is not great precision in parent reports or self-reports of myopia, which are usually based solely on whether the subjects wears glasses prescribed to correct for myopia. By this simple dichotomous definition, myopia is diagnosed by a somewhat uncertain cutting score on the continuous distribution of optical refraction. The present study does better by measuring the degree of refraction directly as a metric variable.

Materials and methods

Subjects

Along with their siblings closest in age, academically gifted students were recruited as volunteers from participants in the Center for Talented Youth's (CTY) 1983 and 1984 Talent Searches at The Johns Hopkins University. A total of 60 sibling-pairs took part in the study. The members of each pair were unrelated to the members of every other pair in the sample. Subjects were not tested in groups or in separate series according to their classification as gifted probands or their siblings, but were tested, both optometrically and psychometrically, in a more or less random order as appointments were individually scheduled at the subject's convenience. Of the 60 sibling-pairs composing the study sample, 19 pairs were brothers, 13 pairs were sisters, and 28 pairs were brother-sister.

Gifted (G). The gifted (G) group consisted of 60 subjects with a mean age of 14 years 10 months (SD = 7 months).

Qualifying for the CTY Talent Search required that students in the selected group be in the top 3% of their age group with respect to psychometrically assessed reasoning abilities. Participating in the Talent Search meant taking the College Board's Scholastic Aptitude Test (SAT) as seventh graders (or in higher grades, but of seventh-grade age). The SAT is a test of mathematical and verbal reasoning abilities and writing skills normally given to college-bound high school juniors and seniors. The G group compares favorably with the select norm group of college-bound high school seniors on the SAT-Verbal and the Test of Standard Written English (TSWE). At junior-high age, students in the G group significantly outperformed the norm group of able students years older than they on the SAT-Mathematical. By virtue of their performance on the SAT, the members of the G group can be considered among the top 1% of their age peers in academic aptitude. This is roughly equivalent to IQs above 135.

Siblings (S). The sibling (S) group included the natural, full siblings who were closest in age to their respective gifted (G) brothers or sisters. The S group consisted of 60 subjects (recruited along with their G siblings) with a mean age of 13 years 5 months (SD = 2 years 9 months).

Because the members of the G groups were all seventh-grade students in 1983 or 1984, the S groups varied more in age than their respective G groups. The G and S groups differed (G > S) significantly ($P < 0.01$) in mean age, a fact that calls for statistical control of age in all the data analyses.

Psychometric tests

The Raven Standard Progressive Matrices (SPM) and Advanced Progressive Matrices (APM) were administered without time limit to all subjects individually by one psychologist, who had no knowledge of the optometric test results or the subjects' group membership. The Matrices are nonverbal power tests of reasoning ability and are known to be highly correlated with the general factor, or *g*, that is common to all complex tests of cognitive ability (Paul 1986).

Optometric tests

All the subjects in groups G and S were given an eye refraction tests to determine the degree of nearsightedness or farsightedness characterizing their vision in each eye. The American Optical SR-IV Programmed Subjective Refractor (Guyton 1982), a compact, computerized instrument designed to perform endpoint subjective refractions by automation of conventional refracting techniques, was employed for this purpose by ophthalmologists in the Wilmer Eye Clinic at The Johns Hopkins Medical Institutions. The ophthalmologist who conducted the examination of all the subjects did not participate in other aspects of the study and was uninformed of the subjects' G or S classification and psychometric scores.

The refraction test yields a spherical equivalence score for each eye (RSEQ and LSEQ for the right and left eyes, respectively). Spherical equivalence scores less than zero indicate the presence of myopia (nearsightedness). The greater the absolute value of the score, the more pronounced the myopic effect. Similarly, a spherical equivalence score greater than zero indicates the presence of hyperopia (farsightedness), and the greater the value of the score, the more pronounced the hyperopic effect.

Questionnaire

Subjects in G and S groups completed a questionnaire concerning their reading and study habits such as frequency of reading, amount of time spent reading per day, and size of print.

Results

Differences between groups

In selecting academically talented students (G) and their siblings (S), we anticipated that the S group would be more intellectually able than average but less able than the G group. Table 1 summarizes the group differences. Because the G and S groups in both studies differ significantly in age, age-standardized scores on both the psychometric and optometric variables are used in all comparisons of G and S. All variables listed in Table 1 (except books read and hours studied) showed a linear (first-order) correlation with age. No significant nonlinear or higher order (second or third) correlations were found. Age standardization removes the linear component of the regression of a given dependent variable on age, making the variable uncorrelated with age.

Psychometric variables. On the 60-item Raven SPM test, G outscores S significantly ($t = 5.11$ $P < 0.01$). The effect size is equivalent to $0.93\,s$, where s is the standard deviation of the pooled G and S groups. On the more difficult 36-item APM test, similar significant differences were found between the G and S groups ($t = 4.93$, $P < 0.01$), with an effect size equivalent to $0.90\,s$. The G group score slightly above the mean for undergraduates at the University of California, Berkeley (Paul 1986), even though the members of the G group are, on

Table 1. Differences between gifted children and their siblings on psychometric, chronometric, and optometric variables, and reading characteristics (age standardized scores are scaled as raw scores). * $P < 0.05$, ** $P < 0.01$

Variable[a]	Gifted		Sibling		Corre-lated *t* test	Effect size[b]
	Mean	(SD)	Mean	(SD)		
SPM	55.1	(2.1)	51.5	(4.8)	5.11**	0.93
APM	27.8	(3.4)	23.5	(6.0)	4.93**	0.90
RSEQ	−113.6	(237.2)	−59.8	(182.5)	−2.00*	−0.37
LSEQ	−112.9	(243.8)	−53.3	(166.2)	−2.22*	−0.41
Books read	12.5	(11.2)	13.8	(19.8)	−0.87	−0.16
Hours studied	1.8	(1.1)	1.9	(1.1)	−0.44	−0.08

[a] SPM, Raven's Standard Progressive Matrices; APM, Raven's Advanced Progressive Matrices; RSEQ, spherical equivalence of right eye; LSEQ, spherical equivalence of left eye; Books read, no. of books read in 3-month period, Hours studied, hours spent studying per day

[b] Effect size (s) is expressed in units of the standard deviation (SD) of the pooled G and S groups, i.e., $s = (\overline{X}_G - \overline{X}_S)/SD$

Table 2. Comparison of gifted (G) group and sibling (S) group on three variables related to nearwork – frequency of reading, duration of reading and print size

Group[a]	Frequency of reading				Significance
	Very much	Much	Little	Not at all	
G (51)	21	23	13	0	$\chi^2 = 2.49$, NS
S (58)	15	26	16	1	
	Duration of daily reading (d)				
	> 3 h	1 h ≤ d < 3 h		d < 1 h	
G (54)	5	27		21	$\chi^2 = 7.25, P < 0.03$
S (59)	2	19		38	
	Print size				
	Small		Large		
G (55)	50		5		$\chi^2 = 0.07$, NS
S (58)	52		5		

[a] The number of subjects (out of the total of 60) who responded to each of the questionnaire items is given in parentheses

the average, 5–6 years younger than the university students. The smaller variance of both the SPM and APM scores in the G group than in the S group, of course, reflects the fact that the G group was explicitly selected from a very restricted range at the top 3% of the distribution of intelligence in the general population. It would seem undesirable to obscure this real difference in variances by transforming the test scores to obtain greater homogeneity of variances, especially in view of the fact that heterogeneity of variances has a statistically negligible effect on the *t* test when the contrasted groups are of equal size (Scheffé 1959).

Optometric variables. Previous research has shown a positive relationship between myopia and intelligence in the general population. Differences in spherical equivalence scores, shown in Table 1, between the 60 sibling pairs composing the G and S groups further support these findings. For both right and left eyes (RSEQ and LSEQ, respectively), correlated *t* tests showed that the G group exhibited significantly greater myopia than the S group ($t = 2.00$, $P < 0.05$; $t = 2.22$, $P < 0.05$, respectively) by effect sizes of 0.37 *s* and 0.41 *s*.

Reading characteristics

As shown in the bottom of Table 1, there were no significant differences between the G and S groups in number of books read in the 3 months prior to participating in the study or in number of hours typically spent studying per day.

Also, there were no statistically significant differences between the G and S groups in their frequency of reading or in the size of print typically read, as summarized in Table 2. The G group, however, reported spending significantly more time reading per day than did the less able S group ($X^2 = 7.27$, $df = 2$, $P < 0.03$). Althoug the latter variable was significant, it was the only significant difference among five comparisons, which seems rather weak evidence for an association between myopia and reading habits. The fact that the G and S groups differed almost one standard deviation on the nonverbal Raven matrices test, which is unrelated to the kinds of knowledge or specific skills acquired through reading, makes it unlikely that any difference in their reading habits was a prior cause of their difference in mental ability. It seems more likely that members of the G groups elected to spend more time in reading because of their greater aptitude and interest in intellectual pursuits. As for the hypothesis that reading or nearwork is a cause of myopia, a large-scale study (Ashton 1985a) specifically addressed to this hypothesis found no support for it.

Discussion

Because mental ability was the sole criterion for selection of the gifted probands, their siblings would be expected to regress toward the mean in ability, as was indeed found. If mental ability and myopia were independent, there should be no regression for myopia, and the mean myopia should be the same in the G and S groups. But, in fact, there was also found significant regression for myopia, with S showing significantly less myopia than G. The finding that the gifted group and their siblings of lesser ability differed significantly and substantially (an effect size of about 0.4 SD) on a measure of optical refraction, with the gifted being more myopic, clearly indicates that the relationship between myopia and mental ability is a within-family relationship. In this respect, the present data are in accord with the study by Benbow (1986), which found a greater incidence of myopia in highly precocious children than in their siblings.

In view of the substantial and well-established broad-sense heritability of intelligence (Plomin 1988; Scarr and Carter-Saltzman 1982) and a preponderance of evidence for the genetic determination of myopia (see Introduction), we suggest that a likely explanation of the association between myopia and intelligence is pleiotropy attributable to some of the genes affecting both traits. There are, of course, other possible models of the association that invoke entirely separate genetic determination of either intelligence or myopia but causally connect these phenotypic traits through environmental pathways. These models involving exclusively environmental pathways could be dubbed "pleiotropy in the broad sense," as contrasted with "pleiotropy in the narrow sense," in which the association between distinct phenotypic traits is attributable mainly to their having some of the same genes in common. Models of the causal path linking IQ and myopia that involve "broad" pleiotropy have been discussed in the literature (e.g., Rosner and Belkin, 1987). The two main alternative hypotheses are that (1) genetically determined myopia leads to a preference for close work and studiousness, which in turn leads to higher performance on IQ tests, and (2) genetically and environmentally conditioned higher IQ leads to a preference for reading and studiousness, which in turn strains the eyes, causing myopia. The second link of the first hypothesis lacks plausibility because it posits a weak cause (studiousness) for a large effect in the case of intellectually gifted and their siblings, who differ almost one standard deviation on a test of intelligence that does not involve reading comprehension or bookish knowledge. No one has yet demonstrated any environmental intervention that will raise the IQ by anything near one standard deviation (Spitz 1986). Hence the second hypothesis seems more plausible than the first, although it must be recognized that the evidence is quite inconclusive that reading, near-work, or studiousness are among the causes of myopia, and most modern investigators have discounted this "near-work" hypothesis of the relation between IQ and myopia. Studiousness per se has not yet been adequately measured or investigated in relation to myopia. But we note that in the present study sample the gifted subjects reported even slightly less time spent in study than was reported by their intellectually less able siblings (see Table 1). Therefore, considering the various explicit hypotheses that have been suggested, we deem "narrow" pleiotropy as the most plausible. Although the probably complex causal pathway underlying even a "narrow" pleiotropic effect is not as yet established, the existence of a WF relationship suggests that a greater understanding of the basis of myopia, or of variation in ocular refraction generally, might lead to the discovery of a physiological basis for the component of the variance in mental ability that is shared with variance in ocular refraction.

Further studies of the association of various physical traits with mental giftedness and with variance in abilities in general, conducted in a within-families design, might suggest promising leads toward discovery of the physiological basis of individual differences in mental ability. A comprehensive theory of intelligence will ultimately have to account for its observed relationship to a number of physical characteristics.

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