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REFRACTIVE ERROR, IQ AND READING ABILITY: A LONGITUDINAL STUDY FROM AGE SEVEN TO 11

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A number of authors have reported an association between refractive error (often measured in terms of defects in visual acuity) and tests of IQ and educational attainment. While the nature of the association remains unclear, there is evidence that some of the differences may be attributable to social class and that differences in IQ and reading ability may exist before the onset of refractive error.

Peckham *et al.* (1977), using a large sample of children from the National Child Development Study, reported that at age 11 children with myopia had higher mean scores for reading, arithmetic and general abilities than children without myopia. They also found that myopia which was acquired or had developed between the ages of seven and 11 was more common among children from families in which the father had a non-manual occupation. However, even after adjusting for differences in social background and the number of older and younger siblings, they found that the children with myopia were ahead by 1·6 years for reading, one year for arithmetic and 1·3 years for general ability. Those authors also noted that before most of the children had become myopic they had already shown an advantage of approximately six months for reading and arithmetic at age seven.

In a more recent British study based on the birth cohort associated with the Child Health and Education Study, Stewart-Brown *et al.* (1985) also found that children with myopia scored higher on the British Abilities Scales and reading and arithmetic tests than children who were not myopic. Again, the ability differences remained statistically significant after adjusting for social class and sex differences.

In an earlier study, Karlsson (1975) showed that the mean IQ of 17- to 18-year-old high-school students with myopia was 10 points higher than that of non-myopic students on a verbal scale and seven points higher on a non-verbal scale. He also reported that differences in IQ 10 years earlier suggested that the intellectual superiority was present before the onset of myopia. Karlsson used a variety of methods to assess refractive error, including cumulative records of visual acuity tests, photographs of the children in the school year-books (which indicated whether or not they wore spectacles with concave lenses) and information from the children and their families.

In a smaller New Zealand study, Grosvenor (1970) reported significant

Developmental Medicine and Child Neurology, 1988, 30, 735–742

differences on the Otis Self-administered Test of General Ability between children with myopia and those with hypermetropia. However, the differences on a second test of general ability, Raven Progressive Matrices, was not significant. Grosvenor's sample of 290 children was divided into three groups—myopes, emmetropes and hypermetropes—on the basis of the refractive error in the right eye. A myope was defined as a child whose refractive error was $-1 \cdot 00$D or more, while a hypermetrope had a refractive error of $+1 \cdot 00$D or more.

Both the British studies (Peckham *et al.*, Stewart-Brown *et al.*) used distance visual acuity as a measure of myopia, which failed to exclude disorders such as amblyopia and hypermetropic astigmatism. For example one of the children in this study had 4 dioptres of astigmatism. Near visual acuity was used as a measure of hypermetropia in the study of Stewart-Brown *et al.*, which ignores the fact that accommodation by 10-year-olds could easily overcome the effects of that refractive error. Grosvenor (1970) failed to use cycloplegic refraction and consequently may have underestimated the size of the hypermetropic group.

Although Peckham *et al.* (1977) and Karlsson (1975) reported earlier differences, neither study carried out appropriate statistical tests to determine whether later differences were explained by the earlier ones. It may be that experiences and activities associated with the onset of myopia also contribute to change in cognitive abilities.

The present longitudinal study was undertaken to provide further evidence on the nature of the association between refractive error and cognitive abilities. Of particular interest was whether differences similar to those observed at age 11 were observed when the children were seven years old and, if so, whether later differences could be explained by the earlier differences. The second major question was whether differences in cognitive ability were simply a by-product of differences in social background, as reported in earlier studies.

The use of cycloplegic refraction to identify the myopic and hypermetropic groups, as well as to define a pre-myopic group, makes this a unique study of the association between refractive error and developmental measures.

Method

Sample

The sample consisted of 537 children, all of whose eyes were refracted under cycloplegia by an optometrist as part of their 11-year-old assessment by the Dunedin Multidisciplinary Health and Development Research Unit. These children were part of a birth cohort born between 1st April 1972 and 31st March 1973 at Queen Mary Hospital, Dunedin's only obstetric hospital. To be eligible for inclusion in the sample, the child's mother had to be resident in the Dunedin urban area at the time of the child's birth. 1139 children were traced around the time of their third birthday, and consent was given for 1037 of these to take part in the study. There has been some attrition since then, but at age 11, 925 (89 per cent) of the children took part in the study. 803 of these were seen at the study centre in Dunedin: the rest were seen at home or by psychologists in other parts of the country or abroad.

Arrangements for a visit to an optometrist were made when the children were seen at the study centre. Although only 537 children were seen by an optometrist, these children did not differ from the rest of the sample in terms of sex, socio-economic status, or distance visual acuity measured at 4m on a logarithmic test-chart. Neither were their IQ scores or reading scores significantly different from those of the rest of the sample.

The sample has been described in detail by McGee and Silva (1982). It is known to be representative of Dunedin children, but socio-economically advantaged compared with New Zealand as a whole. It is also under-representative of Maori and Polynesian children. The children have been seen by the Research Unit every second year since their third birthday. On each occasion they have participated in a variety of assessments such as psychological and educational tests, hearing and vision tests, measures of blood-pressure and anthropometric variables. A parent, usually the mother, has also completed comprehensive questionnaires. Informed consent was given by a parent for each procedure.

Classification of visual defects
The children were divided into five groups on the basis of their refractive errors, as measured by the optometrists. The first group of children, designated as myopic, had a refractive error of $-0 \cdot 25$D or more in at least one eye, the better eye being emmetropic or hypermetropic. The second group of children, who were considered to be at risk of developing myopia, had a refractive error of between plano and $+0 \cdot 50$D in both eyes. The third group, those with hypermetropia, had a refractive error of more than $+2 \cdot 25$D in both eyes. A fourth group, who required either a horizontal prism of 12Δ or more or a vertical prism of more than 1Δ, and who had convergence problems or astigmatism greater than $1 \cdot 0$D, were described as having 'other problems'. The fifth group had none of these visual problems.

Psychological and educational measures
As part of their assessments at seven and 11 years, the children completed the WISC-R IQ test (Weschler 1974). Because of time constraints, Comprehension, a verbal IQ subtest, and Picture Arrangement, a performance IQ subtest, were omitted. The scores for the remaining tests were pro-rated according to the instruction in the manual. The IQ scores were restandardised so that the whole sample had a mean of 100 and a standard deviation of 15. The children also completed the Burt Word Reading Test (Scottish Council for Research in Education 1974).

Parental and family characteristics
Socio-economic status was recorded at the child's nine-year examination. The index, based on the father's occupation, has been described by Elley and Irving (1976). The scale has six categories, the two highest including professional and managerial occupations and the two lowest semi-skilled and unskilled occupations. Categorical variables based on these categories were used for the statistical analysis. Because socio-economic status was based on the father's occupation, it was an inappropriate measure for about 10 per cent of the sample with solo mothers.

Maternal intelligence was assessed when the children were three years of age with the SRA Verbal Test (Thurstone and Thurstone 1973). The Family Relations Index, which is a weighted sum of the expressiveness, cohesion and conflict scales of the Family Environment Scale (FES) (Moos 1974), was used to provide a measure of family support and openness about opinions and feelings. Other scales included the intellectual and cultural orientation subscale, a measure of interest in political, social, intellectual and cultural activities, and the achievement orientation subscale, which measures the extent to which activities are set in a competitive framework. This questionnaire was completed by the mothers at the time of the children's seven-year assessment. Family size and the child's ordinal position in the family were also recorded.

Statistical analysis
There were two issues of interest relating to the IQ and reading measures, namely whether there were differences among the groups at either age seven or 11 years, and whether or not there had been relative changes among the groups between the two ages. Plewis (1985) has argued that the most appropriate form of analysis to examine change over time is a conditional model based on a regression approach. This type of model examines the degree of relative change in a particular measure for two or more groups on two occasions by setting the groups equal on the first occasion and by treating the measures on the first occasion as fixed and examining the distribution of measures on the second occasion for fixed values of the first measure. This is done by finding a linear regression equation which models the relationship between the variables measured on the second occasion with the relationship on the first. Conditional models also have the advantage of taking account of the direction of time, and allow one to use one's knowledge of the past when making predictions about the future. The effects of other variables of interest (*e.g.* sex or maternal verbal ability) can be examined by including

Developmental Medicine and Child Neurology, 1988, 30, 735–742

TABLE I
Family background measures

	Myopic (N=23)		Pre-myopic (N=64)		Hyper-metropic (N=26)		No refractive error (N=390)		EMS†	Test statistic
	N	%	N	%	N	%	N	%		
Sex (boys)	15	65·2	32	50·0	9	34·6	214	54·7		χ^2(3df)= 4·86
Socio-economic status										
High (levels 2 and 2)	7	30·4	12	18·7	5	19·2	96	24·6		χ^2(6df)= 4·85
Low (levels 5 and 6)	1	4·3	8	12·5	3	11·5	48	12·2		
Solo mothers	2	8·7	9	14·1	5	19·2	9	4·8		χ^2(3df)=14·16*
Family size										
1 or 2 children	14	60·9	27	42·2	10	38·5	160	41·0		χ^2(6df)= 7·81
3 children	5	21·7	26	40·6	7	26·9	136	34·9		
4 or more children	4	17·4	11	1·6	9	34·6	94	24·1		
Ordinal position										
1st child	12	52·2	30	36·9	9	34·6	131	33·6		χ^2(9df)=14·95
2nd child	8	34·8	17	26·6	6	23·1	140	35·9		
3rd child	1	4·3	11	17·2	8	30·8	58	14·9		
4th or later	2	8·6	6	9·4	3	11·5	6	15·6		
Maternal verbal ability	50·6		40·8		31·8		39·7		14·36	F(3,502)=6·88*
Family Relations Index	20·9		18·0		18·0		19·3		3·55	F(3,502)=5·37*
Cultural and intellectual orientation	5·9		5·6		5·0		5·8		1·75	F(3,502)=1·41
Achievement orientation	3·7		4·5		4·3		4·2		2·05	F(3,502)=1·34

†Error root mean square. *p<0·05.

TABLE II
Mean Verbal IQs of children with and without refractive errors

Verbal IQ	*Myopic (N=23)*	*Pre-myopic (N=64)*	*Hyper-metropic (N=26)*	*No refractive error (N=390)*	*EMS†*	*F*
At age 7	103·0	102·6	95·4	100·0	13·81	1·76
At age 11	106·5*	103·6*	92·6*	100·4	13·30	5·50*
At age 11, adjusted for VIQ at 7	105·3*	102·6	96·2	100·4	10·02	4·04*
At age 11, adjusted for maternal verbal ability and Family Relations Index	102·6	104·1*	95·5	100·3	9·91	3·12*

†Error root mean square. *p<0·05.

TABLE III
Mean Performance IQs of children with and without refractive errors

Performance IQ	*Myopic (N=23)*	*Pre-myopic (N=64)*	*Hyper-metropic (N=26)*	*No refractive error (N=390)*	*EMS†*	*F*
At age 7	109·5*	103·4	97·8	101·1	14·04	3·51
At age 11	108·4*	103·8*	95·0*	100·6	13·51	4·81*
At age 11, adjusted for Performance IQ at age 7	103·5	102·7	97·3	100·9	10·47	2·00

†Error root mean square. *p<0·05.

them in the model. Because the three measures of interest were known to be correlated, we decided to use the Bonferroni inequality (Hall and Bird 1985) to maintain the experimental or family-wise error rate at 5 per cent. In this case a decision-wise error rate of 0·017 (0·05/3) was used.

Analysis of variance or χ^2 tests were used to test the hypotheses relating to the family background measures. The Scheffé *post hoc* procedure was used to examine differences between means, where appropriate.

Results

By age 11, 23 of the total 537 children (4·3 per cent) had developed myopia. 17 of these 23 had normal distance visual acuity at age seven. There were 66 pre-myopic children (12·3 per cent), who had refractive errors between 0 and +0·50D; and 26 children (4·8 per cent) with hypermetropia. A further 31 children (5·7 per cent) had other eye problems. The remaining 391 children had no significant refractive error.

The 31 children with other eye problems and those with a Full-scale IQ less than 70 were excluded from further analysis. This left totals of 23 myopic children, 64 pre-myopic, 26 hypermetropic, and 390 children with no refractive error.

The results for the family background variables are shown in Table I. There were no statistically significant differences between the groups in sex or socio-economic status. However, there were significant differences in solo parents, these being more common in the pre-myopic and hypermetropic groups. There were also significant differences between the groups in maternal verbal ability: *post hoc* tests showed the mothers of the children with myopia to have significantly higher scores than the mothers in the rest of the sample. There were also statistically significant differences between the groups on the Family Relations Index, though *post hoc* tests did not indicate differences between any particular pair of means. Differences between the groups on the cultural and intellectual orientation scale and the achievement orientation scale of the FES were not significant, nor were there statistically significant differences in family size or ordinal position of the child in the family.

The results for Verbal IQ scores are shown in Table II. At age seven the differences between the groups were not statistically significant, but there were significant differences at age 11. The means for both the myopic and pre-myopic groups were higher than the mean for children without visual problems, while the hypermetropic children did significantly less well than those with no significant refractive error. When a regression model including the seven-year measure of Verbal IQ was used, the differences between the groups at age 11 remained statistically significant. Examination of *post hoc* contrasts between each group and the group without visual problems showed that there was a significant relative increase in Verbal IQ between the ages of seven and 11 for the children with myopia. When the variables measuring maternal verbal ability and the Family Relations Index were included in the model, the differences between the groups were still significant; however, the only *post hoc* contrast was that between pre-myopic children and the rest of the sample. There was no evidence to suggest that Verbal IQ changed at a different rate for boys than for girls.

The means for the Performance IQ scores for the four groups are shown in Table III. There were statistically significant differences among the groups at both ages seven and 11: at both ages the children with myopia had significantly higher scores than those without visual problems. At age 11 the children with hypermetropia had significantly lower scores, while the pre-myopic group did better than the children without visual problems. When the seven-year Performance IQ score was included in the model the differences between the groups at age 11 were no longer significant, implying that the differences at age 11 were attributable to the differences at age seven.

It has been suggested that the variables which measure maternal verbal ability and the Family Relations Index are proxy variables for socio-economic status, so perhaps it should be noted that correlations between them and socio-

Developmental Medicine and Child Neurology, 1988, 30, 735–742

TABLE IV
Mean Burt Reading scores of children with and without refractive errors

	Myopic (N=23)	*Pre-myopic (N=64)*	*Hyper-metropic (N=26)*	*No refractive error (N=390)*	*EMS*†	*F*
At age 7	34·7	32·9	26·3	30·0	12·74	2·58
At age 11	76·5	77·1	65·3	72·1	19·39	2·62

†Error root mean square.

economic status were low, 0·25 and 0·04, respectively.

The results for the Burt Reading Test are shown in Table IV. There were no significant differences between the groups at either age seven or 11.

Discussion

The association between high IQ, scholastic achievement and myopia reported by Karlsson (1975), Peckham *et al.* (1977) and Stewart-Brown *et al.* (1985) was confirmed in the present study. In addition, hypermetropia was associated with the opposite pattern of results, *i.e.* lower IQ and achievement. The IQ differences at age 11 were substantial and not merely statistically significant. Differences between the myopic and hypermetropic children were of the order of a full two-thirds of a standard deviation, or 10 IQ points. Furthermore, the mean IQ of the myopic group was approximately one-third to one-half of a standard deviation above the mean of the group with no vision defects, while the hypermetropic children's mean was below the mean for those with no vision problems by a similar amount. This pattern of results suggests an association between IQ and ocular refraction along the continuum of refractive error.

In the case of Verbal IQ, a difference of seven IQ points at age seven between myopic and hypermetropic children had doubled by age 11. Furthermore, the Verbal IQ differences between the groups at age 11 were not attributable simply to the differences existing at age seven. These data therefore are consistent with the hypothesis that experiences associated with the onset and development of refractive error may be causally related to increases in Verbal IQ. However, this result should be viewed with caution for at least two reasons. First, significant IQ gains were apparent only in the 'high risk of myopia' group once maternal verbal ability and family relations were partialled out. Second, no similar divergence between the myopic and hypermetropic groups was observed for either Performance IQ or reading achievement. Nonetheless, this appears to be the first report of IQ change associated with the onset or progress of myopia. It could be speculated that, following the onset of myopia, activities such as reading, which require near visual acuity, tend to become more frequent relative to activities requiring distance vision. There is evidence that reading ability can lead to long-term changes in Verbal IQ (Bishop and Butterworth 1980) and in general vocabulary (Nagy *et al.* 1985). There is also evidence that differences in reading ability are associated with differences in the volume of in-school reading (Allington 1977). In the present study, however, there was no evidence to support the notion that changes in reading ability between the ages of seven and 11 explain the divergence in IQ over that period. Although myopic children tended to be better readers and hypermetropic children poorer readers than children without vision problems at both ages, these differences were not statistically significant, nor was there any evidence of relative change between seven and 11. For the present, therefore, the interpretation of the changes in Verbal IQs must await further investigation.

Unlike Verbal IQ, the Performance IQ data showed no evidence of relative change over time. Both the lower Perormance IQ scores of the hypermetropic children and the higher scores of the myopic children at age 11 were attributable to differences apparent at age seven. It is difficult to interpret why Verbal and Performance IQs show different patterns of relative change, but it is clear that these two aspects of intelligence need to be considered independently in future investigations.

The differences in socio-economic status reported by Peckham *et al.* (1977) and Stewart-Brown *et al.* (1985) were not found in the present study. This may be attributable partly to the relative homogeneity of socio-economic status in the Dunedin sample (McGee and Silva 1982). There was a clear-cut difference between the groups in the home background characteristic of maternal mental ability, but not on home environmental measures such as socio-economic status, solo parents, family size or birth order. The finding that the stongest association between background characteristics and refractive error was maternal mental ability rather than the environmental measures raises the possibility that the oft-reported association between high socio-economic status and myopia may be due partly to socio-economic status acting as a proxy for parental intelligence.

It is planned to re-examine the pre-myopic children in this study around the time of their fifteenth birthdays to determine whether they have become myopic.

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SUMMARY
Children from a population sample whose cycloplegic refractive errors included myopia, pre-myopia and hypermetropia were compared on measures of IQ and reading with a group of children without significance refractive errors. At age 11 both those with myopia and with pre-myopia had increased verbal and performance IQ, while those with hypermetropia had slightly reduced verbal and performance IQ, in comparison with the children without refractive errors. The differences in verbal IQ were not attributable simply to earlier differences, but the differences in performance IQ were attributable to earlier differences. No significant differences in reading scores were found at either age. It is concluded that differing abilities of myopic and other children at age 11 are not fully explained by differences in family background or in pre-existing ability.

RÉSUMÉ
Défaut de réfraction, QI et capacité de lecture: étude longitudinale de sept à 11 ans
Des enfants provenant d'un échantillon dont les défauts de réfraction cycloplégiques incluaient la myopie, la pré-myopie et l'hypermétropie ont été comparés en termes de QI et d'efficience de lecture avec un groupe d'enfants sans troubles significatifs de réfraction. A l'age de 11 ans, les QI verbaux et de performance étaient élevés chez les enfants porteurs de myopie et de pré-myopie, légèrement inférieurs chez les hypermétropes, par comparaison avec les enfants sans défauts de réfraction. Les différences dans les QI verbaux n'étaient pas attribuables seulement aux différences antérieures, au contraire des différences pour le QI de performance. Aucune différence significative dans les scores d'efficience de lecture n'a été notée à aucun age. Les auteurs concluent que la différence d'aptitude chez les enfants myopes et autres à 11 ans ne sont pas totalement explicables par des différences de milieu social ou de capacités antérieurs.

ZUSAMMENFASSUNG
Refraktionsfehler, IQ und Leseleistung: eine Langzeitstudie von sieben bis 11 Jahren
Eine Gruppe von Kindern, deren cycloplegische Refraktionsfehler Myopie, Prämyopie und Hypermetropie beinhalteten, wurden anhand des IQ und der Leseleistung mit einer Gruppe von Kindern ohne signifikante Refraktionsfehler verglichen. Im Alter von 11 Jahren hatten die mit Myopie und mit Prämyopie erhöhte Verbal und Performance IQs, während die mit Hypermetropie leicht erniedrigte Verbal und Performance IQs im Vergleich zu den Kindern ohne Refraktionsfehler hatten. Die Unterschiede beim Verbal IQ waren nicht nur früheren Unterschieden zuzuordnen, aber

die Unterschiede beim Performance IQ waren früheren Unterschieden zuzuordnen. Die Lesescores wiesen in keiner Altersstufe signifikante Unterschiede auf. Die Autoren sind der Meinung, daß abweichende Leistungen bei myopischen und anderen Kindern nicht ausreichend durch Unterschiede des familiären Hintergrunds oder von bereits vorhandenen Fähigkeiten erklärt sind.

RESUMEN

Error de refraccion, CI y habilidad para la lectura: estudio longitudinal de los siete a los 11 años de edad

Niños de una muestra de población cuyos errors de refracción cicloplégicos incluían myopía, premiopía e hipermetropía fueron comparados, en las mediciones de su CI y lectura, con un grupo de niños sin ningún error de refracción significativo. A la edad de 11 años los que tenían miopía y premiopía habían aumentado su CI verbal y manipulativo mientras que los con hipermetropía tenían una ligera disminución en el CI verbal y manipulativo en comparación con niños sin errores de refracción. Las diferencias en el CI verbal no eran atribuibles solamente a diferencias anteriores, pero sí lo eran las diferencias en el CI manipulativo. No se hallaron diferencias significativas en los puntajes de lectura en ninguna edad. Se concluye que las diferencias en las habilidades de niños miópicos y otros niños a la edad de 11 años no se explican plenamente por diferencias familiares o por habilidades preexistentes.

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