Association of visual acuity with educational outcomes

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Title: Association of visual acuity with educational outcomes: a prospective cohort study

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Synopsis/Precis:

In this school-based cohort study, better baseline presenting visual acuity, but not refractive error or spectacle wear, was a significant predictor of later academic performance, suggesting a significant association between vision and academic outcomes.

Abstract

Background/Aim: To quantify the impact of baseline presenting visual acuity (VA), refractive error, and spectacles wear on subsequent academic performance among Chinese middle school children.

Methods: A prospective, longitudinal, school-based study on grade 7 Chinese children (age, mean ± SD, 12.7 ± 0.5 years, range= 11.1, 15.9) at 4 randomly-selected middle schools in Anyang, China. Comprehensive eye examinations including cycloplegic autorefraction were performed at baseline, and information on demographic characteristics, known risk factors for myopia, and spectacle wear was collected. Academic test scores for all subjects in the curriculum were obtained from the local Bureau of Education. Main outcome measure was total test scores for 5 subjects at the end of grade 9, adjusted for total scored at the beginning of grade 7.

Results: Among 2363 eligible children, 73.1%(1728/2363) had 7th grade test scores available. 93.9%(1623/1728) completed eye examinations, and 98.5%(1599/1623) of these had 9th grade test scores. Adjusting only for baseline test score, the following were significantly associated with higher 9th grade scores: younger age, male sex, less time outdoors, better baseline presenting VA and higher parental education, myopia and income, but refractive error and spectacle wear were not. In the full multivariate model, baseline test score ($p<0.001$), presenting VA ($p=0.006$), age ($p<0.001$), quality of life ($p=0.036$), and parental education ($p<0.001$) and myopia (either: $p=0.03$; both: $p=0.03$) remained significantly associated with better 9th grade scores.

Conclusions: In this longitudinal study, better presenting VA, but not cycloplegic refractive error or spectacle wear, was a significant predictor of subsequent academic performance.

Introduction

Education is a basic human right.[1] Among the goals of the United Nation's Educational, Scientific and Cultural Organization's (UNESCO) Education for All program is "Ensuring that the learning needs of all young people...are met through equitable access to appropriate learning."[2] Poor vision is a major barrier to achieving a healthy and educationally-sustaining school environment for children in many regions of the world today.[3-8]

Because of the complex, bidirectional relationship between refractive error and visual acuity (VA) on the one hand and academic performance on the other, cause and effect inference is generally difficult to draw with any certainty from cross-sectional studies.[9] The complexity of this topic is due largely to the fact that refractive errors in school going children, which in the setting of China is largely due to myopia, is itself strongly associated with academic outcomes: myopia and academic achievement appear to be linked, potentially with causality proceeding in both directions. One approach to elucidate the nature of the association is randomized trials of the impact of interventions designed to improve visual acuity on academic outcomes. One such trial has demonstrated a statistically significant difference in mathematic scores between children provided with free spectacles compared to those given a prescription for glasses only (control group) .[6] However, the effect may be diluted due to poor compliance. Furthermore, mathematics score may not represent overall academic performance. Another approach is prospective studies examining the association between baseline VA and subsequent academic performance. Several longitudinal studies suggest visual interventions such as spectacle provision can improve academic performance, particularly in young, hyperopic children.[5,7,10] However, these studies are either small (n<100)[7,10] or focus on special populations of children,[11] and there are some conflicting results.[11,12] Moreover, no large, longitudinal studies have been carried out among children in China, who account for half of all paediatric visual impairment due to uncorrected refractive error worldwide.[13]

We performed a longitudinal, school-based study of a large cohort of children in a middle-income Chinese city, Anyang (where middle school enrolment rate was over 99%), to quantify the impact of baseline presenting VA, refractive error and spectacle wear on subsequent academic performance in all five main subjects in the Chinese national standard middle school curriculum. We hypothesised that better presenting VA at baseline would predict better academic performance after three years of study among middle school children.

Methods

Ethical approval was obtained from the institutional review board of Beijing Tongren Hospital, Capital Medical University (Beijing, China), and the study adhered to the tenets of the Declaration of Helsinki. Informed written consent was obtained from at least one parent of all participating children, and verbal assent was provided by each child.

Study Population

The current report is based on the Anyang Childhood Eye Study (ACES), which examined refractive error, other ocular conditions, socioeconomic factors, and academic performance in a school-based sample of grade 1 and grade 7 school children in urban Anyang, Henan Province, Central China. The methods of ACES are reported elsewhere in detail, [14] and are provided here for reference. Four schools were randomly selected from among all eleven middle schools in Anyang city, with stratification based on quality of education evaluated by the local government, in order to derive a representative sample of local schools. All of the 2363 eligible grade 7 students (expected age 12 to 16 years) attending these four schools were invited to undergo screening. Among them, 1998 students (1998/2363, 84.6%) had parental consent for releasing academic test scores and 1728 of these (1728/1998, 86.5%) had test scores available at the local Bureau of Education of Anyang. (Figure 1)

This report examines the association between baseline (beginning of Grade 7) presenting VA and other potential determinants on the one hand and endline (end of Grade 9) academic test results on the other. The study thus covers the entire three-year period of Chinese middle school education (grades 7 through 9).

Examinations

All children underwent a comprehensive ocular examination at baseline (Grade 7), which was repeated using the identical protocol at the end of Grade 9. Distance presenting VA was measured separately for each eye, with and without spectacles, if worn, using a logarithm of the Minimum Angle of Resolution (logMAR) visual acuity chart (Precision Vision, La Salle, IL, USA) at a distance of 4m. The chart was retro-illuminated and had 5 tumbling ‘‘E’’ optotypes on each line. Children who could not read the largest line at 4 metres were tested sequentially as needed at 3 metres, 2 metres, 1 metre, and then for their ability to count fingers, recognize hand movements and perceive light.

For students with distance VA > 0.0 logMAR (Snellen <6/6) in either eye, subjective refraction was performed to obtain best-corrected VA. In such cases, one drop of topical anaesthetic agent (Alcaine, Alcon, Ft Worth, USA), two drops of 1% cyclopentolate (Alcon) followed by one drop of 0.5% tropicamide (Mydrin P, Santen, Japan) were administered twice at five-minute intervals. Cycloplegic autorefraction (HUVITZ, HRK-7000A, South Korea) was performed 30 minutes to 1 hour after the final drop, unless the pupillary light reflex was still present or the pupil size was < 6.0 mm, in which case a third drop of cyclopentolate was given. The mean of five measurements was computed and recorded as the refractive power for each eye. Spectacles wear was defined as wearing spectacles to school on the day of the examination, children having been instructed to do so the day prior.

Questionnaires

Questionnaires[15] were administered to all eligible children by trained interviewers to collect information on parental education, income and myopia, and the child's weekly time spent outdoors, frequency of spectacle wear, age of myopia onset and age of first wearing and frequency of changing spectacles.

A previously-validated Chinese translation of the Paediatric Quality of Life Inventory version 4.0[16,17] was administered to all eligible children. Each question described a possible situation, with potential responses ranging from 0-4, 0 indicating "never a problem" and 4 "almost always a problem."

Measures of academic performance

Test scores were requested for all eligible children from the local Bureau of Education. All students in our study took one set of municipal-level standardized examinations upon entrance to Grade 7, and another at the end of Grade 9. The examination content and syllabi for the 5 subjects did not differ between schools participating in the current study, all of which were public schools.

Statistical methods

Statistical analysis was performed using Stata 14.0 (StataCorp, College Station, TX). Measures are presented as mean ± standard deviation (SD) for continuous variables and percentages for categorical variables. Refractive power was defined as spherical equivalent (SE, sphere power + cylinder power/2). The eye with the better presenting VA (corrected VA if the child presented to the exam with spectacles and uncorrected VA if the child came without spectacles) at the time of baseline examination was defined as the better-seeing eye. Only data from the better-seeing eye were analysed. Baseline characteristics for children who did and did not have follow-up data from Grade 9 were compared using the 2-tailed t-test for continuous variables, chi-square test for categorical variables, and Fisher's exact test for categorical variables if one or more cells had an expected frequency of <= 5.

Associations between baseline predictor variables (presenting VA, refractive error and spectacles wear) and test scores in Grade 9 were investigated using simple and multiple regression models, adjusting for baseline (Grade 7) test score to account for children's inherent aptitude. This approach is preferable to calculating the difference between 7th and 9th grade scores by subtraction, as the latter method tends to give a non-normal distribution, contrary to the assumptions of regression modelling. Other baseline variables were investigated as predictors of Grade 9 test scores after adjusting for baseline score only. Then, all variables significant at the P < 0.05 level were included in the final multiple regression model. Regression coefficients and 95% confidence intervals (95% CI) were presented. All P values were two-sided and were considered statistically significant when < 0.05.

Results

Among 2363 eligible Grade 7 children at baseline, test scores from the beginning of Grade 7 could be obtained for 1728 children (73.1%, 1728/2363; mean age 12.7±0.47 years; 49% boys, 847/1728) from the local Bureau of Education. Among these, 1683 (97.4%, 71.2% of all eligible children) completed visual screening from which information on presenting VA and spectacle wear were obtained, and among these children, 1623 (96.4%, 68.7% of all eligible children) underwent cycloplegic autorefraction. (Figure 1)

Among these 1623 Grade 7 children, 98.5% (1599/1623, 67.7% of all eligible children) provided test scores after three years of study at the end of Grade 9, and among them 79.5% (1272/1599) had data on presenting VA. Lack of follow-up was due to unavailability of test scores from the local Bureau of Education, or as a result of having moved out of the area or failing to take the final examinations. Table 1 compares baseline characteristics of children with and without follow-up at the end of Grade 9. Children lacking follow-up data were significantly older, had lower baseline test scores, were less likely to have a parent with college education, had lower quality of life, were less myopic, less likely to have myopic parent(s), and less likely to wear spectacles, whereas the following characteristics did not differ with follow-up status: gender, parental income, body mass index (BMI), waist circumference, outdoor time, and presenting VA.

At baseline, 345/1728 (20.0%) children had presenting VA ≤6/12 (logMAR≥0.3) in the better-seeing eye. Among the 1623 (1623/1728 or 93.9%) children who underwent cycloplegic autorefraction at baseline, mean spherical equivalent refractive error (SE) in the better-seeing eyes was -1.50±2.02D. Data for glasses wear (yes/no) at baseline were available for 1680 (1680/1728=97.2%) children, and among these, 40.7% (683/1680) wore spectacles. (Table 1).

Before adjusting for baseline test scores, children with moderate visual impairment had better grades than children with no visual impairment (Table 2). Adjusting only for baseline test score, younger age (95% CI= -13.2 to -5.43; p<0.001), male sex (95% CI= 0.09 to 7.31; p<0.05), less time outdoors (95% CI= -1.40 to -0.47; p<0.001), better baseline presenting VA (95% CI= -20.1 to -2.34; p=0.01), and higher parental education (95% CI= 8.46 to 15.9; p<0.001) parental myopia (either parent: 95% CI= 3.04 to 11.6, p=0.001; both parents: 95% CI= 5.62 to 19.9, p<0.001) and income (95% CI= 0.94 to 8.21; p=0.01) were significantly associated with higher 9^{th} grade scores. (Smaller logMAR implies better VA, thus a negative regression coefficient here means that better vision is associated with better scores). Variables without significant association (refractive power, spectacle wear) were excluded from the multi-variable analysis. In the full multivariable model, baseline test score (coefficient=0.854, 95% CI=0.83 to 0.88; p<0.001), presenting VA (coefficient=-12.6, 95% CI= -21.5 to -3.67;p=0.006), age (coefficient=-7.18, 95% CI= -11.2 to -3.19; p<0.001), quality of life (coefficient=-3.68, 95% CI= -7.12 to -0.24; p=0.04), parental education (coefficient=8.04, 95% CI, 4.02 to 12.1; p<0.001), and parental myopia (either: coefficient=4.76, 95% CI= 0.35 to 9.16; p=0.03; both: coefficient=8.19, 95% CI= 0.71 to 15.7; p=0.03) remained significantly associated with better 9^{th} grade scores (Table 3).

Discussion

Our results suggest that presenting VA may be at least as important a predictor of academic performance as parental education and income. This relationship was only clear when adjusting for baseline test scores as an index of children's innate ability, as is commonly done in educational research. The prospective nature of the study is also important in elucidating the nature of the association between vision and test performance, as confounding of this relationship by myopia may occur in cross-sectional studies. Previous research has showed that myopia is linked with higher level of education,[18-20] better academic performance [21-23] and even intelligence.[24,25] However, the prospective nature of the current study provides evidence that baseline good vision may lead to subsequent better academic performance. Being able to see clearly at distance is essential for children to learn, particularly as all of the classrooms in participating schools in our study used blackboards as the main tool of instruction, as in many secondary schools in China.

This is the first study that directly examines the relationship between vision and academic performance in Chinese children. Our results are supported by a published randomised, controlled trial in China on spectacle provision, which found that provision of spectacles, compared to giving prescriptions only, led to improved mathematics scores.[6] Randomised trials provide the strongest possible evidence of causal association, but are expensive and require deferred provision of eyeglasses to control group children, which may be problematic in rural Chinese settings. Spectacle ownership and wear as used in Ma et al 2014 are indirect indications of VA, as they depend on compliance with glasses wear and accuracy of the spectacle lenses themselves. Our study directly used VA as the independent variable. Furthermore, test scores across all subjects (instead of a mathematic only) in the middle school curriculum offers a better representation of students' academic ability. Improved academic performance in a set of tests administered by the governmental education bureau confers a practical benefit because it gives the child a better chance to enter a more competitive high school.

We found no significant association between children's spectacle wear and academic performance when adjusting for baseline test scores in the current study. This lack of association may in part have been due to the relatively low rates of spectacle wear in this setting, or that children's having brought spectacles to the baseline examination when directed may not have been indicative of actual patterns of daily wear.

Findings from our study also corroborated conclusions from studies in different populations. A study in US schools showed that failing vision screening was predictive of being in the lowest quartile of academic performance.[5] A longitudinal study in a group of UK children also found that early developing literacy was directly correlated with the level of VA.[26] In contrast, another longitudinal study in Singaporean children showed that VA was not a significant predictor of academic performance.[12] However, that study did not adjust for baseline test score in their regression models, a shortcoming as noted above.

Parental education was found to be a strong predictor of children's academic performance. This was possibly the result of parents with higher education being more likely to understand the importance of schooling, and being better-equipped to provide their children with necessary resources to perform well. This finding is consistent with results from Chinese[26] and other populations.[27,28]

Strengths of this study include a large sample size drawn from randomly-selected Chinese schools, a prospective design with long period of follow-up, use of a broad-based index of academic performance (including all 5 major courses in the standardized Chinese curriculum), and relatively high rates of follow-up and data completeness. However, this was not a randomized controlled trial, allowing for the possibility of uncontrolled confounding factors, though we took careful precaution to control for many known risk factors of myopia.

Additionally, children owning glasses were instructed to wear their glasses for baseline ocular examination in order to assess presenting visual acuity. This may have caused some underestimation of presenting VA due to under-correction of myopia among children wearing glasses.[29] On the other hand, over-estimation of presenting VA was also possible, particularly among children who did not routinely wear their glasses, but brought them for testing as instructed. Children not wearing their glasses have generally been found to have lower levels of myopia[30], so resulting inaccuracies would tend to be modest. It is most likely that inaccuracy in the characterization of children's usual visual acuity would tend to weaken, rather than strengthen, the observed association between test scores and visual acuity, though this cannot be known for certain.

Despite its limitations, the current report provides suggestive evidence that better vision may lead to enhanced academic outcomes for middle school children. We hope it will provide additional impetus for concerted efforts from government ministries, schools, parents, and health-care professionals to ensure that no child in China is denied access to a good education due to poor vision.

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Table 1. Baseline Characteristics of middle school children participating in a study of the impact of vision and other factors on academic performance in Anyang, China.

Characteristics	All (n=1728)	Missing data n (%)	With follow-up (n=1599, 92.5%),	Without follow-up (n=129, 7.5%)	P-value comparing children with and without follow-up
Total Test Score, mean (SD)	369 (76.7)	0 (0)	375 (72.2)	292 (88.4)	<.001†
Age (years), Mean (SD)	12.7 (.473)	1 (.06)	12.7 (.452)	12.8 (.678)	.010†
Male, n (%)	846 (49.0)	0 (.0)	778 (48.7)	68 (52.7%)	.375‡
At least one parent with some college education, n (%)	567 (32.9)	6 (.3)	543 (34.0)	24 (18.6%)	<.001‡
Family income above national average, n (%)	1,102(63.8)	0 (0)	1,015 (63.5)	87 (67.4%)	.367‡
Body Mass Index (kg/m^2), Mean (SD)	19.8 (3.63)	0 (.0)	19.8 (3.61)	19.7 (3.92)	.847†
Waist circumference (cm), Mean (SD)	70.4 (9.27)	22 (1.3)	70.4 (9.22)	70.4 (9.89)	.972†
Time outdoors (hours/week), Mean (SD)	14.3 (20.7)	0	14.1 (18.0)	17.2 (41.7)	.095†
Paediatric Quality of Life Score, Mean (SD)*	.84 (.52)	24 (1.4)	.829 (.519)	.989 (.554)	.001†
Spherical equivalent refractive error in better-seeing eye (Diopters), Mean (SD)	-1.50 (2.02)	105 (6.1)	-1.54 (2.04)	-1.04 (1.67)	.009†
Presenting visual acuity ≥ 0.3 (logMAR units) in the better-seeing eye, n (%)	345 (20.0)	45 (2.6)	363 (22.7)	27 (20.9%)	.643‡
Parental myopia, n (%)		0 (.0)			.003§
None	1248, (72.2)		1,140 (71.3)	108 (83.7%)	
Either	372 (21.5)		353 (22.1)	19 (14.7%)	
Both	108 (6.3)		106 (6.63)	2 (1.55%)	
Child wearing glasses, n (%)	683 (40.7)	48 (2.78)	648 (40.5)	35 (27.1%)	.001‡

*Paediatric quality of Life Inventory version 4.0 Scores: 0-4 scale, the lower the score the better the quality of life.
†Two-sample t test was used for the comparison.
‡Chi-square test was used for the comparison.
§Fisher-exact test was used for the comparison.

Table 2. Association of presenting visual acuity in the better-seeing eye at the beginning of Grade 7 (entrance to middle school) and academic performance in various subjects on tests administered at the end of Grade 9 (graduation exam of middle school) (Graded from 0-100).

VA (4m, logMAR units)*	GRADE 7 (BASELINE) (out of 1728 with available academic scores, 1683 completed vision screening)							GRADE 9 (ENDLINE) (out of 1599 with available academic scores, 1272 completed vision screening)						
	n screened, (%)	Chinese Mean (SD)	Maths, Mean (SD)	English, Mean (SD)	Politics, Mean (SD)	History, Mean (SD)	Total score, Mean (SD)	n screened, (%)	Chinese, Mean (SD)	Maths, Mean (SD)	English, Mean (SD)	Politics, Mean (SD)	History, Mean (SD)	Total score, Mean (SD)
No VI (VA ≤ 0.1)	1117 (66.4)	76.0 (11.0)	83.1 (18.7)	67.7 (23.1)	69.8 (18.2)	69.8 (21.2)	366.0 (76.5)	741 (58.3)	82.7 (12.8)	72.6 (23.9)	69.2 (28.6)	50.1 (8.70)	31.2 (7.39)	305.8 (72.8)
Mild VI (0.1<VA≤ 0.48)	479 (28.5)	77.8 (10.7)	84.1 (19.2)	69.8 (22.4)	72.2 (18.4)	71.4 (22.0)	375.0 (77.8)	431 (33.9)	84.1 (12.0)	73.5 (21.9)	71.3 (26.0)	50.5 (8.28)	31.7 (7.12)	311.1 (66.5)
Moderate & severe VI (VA>0.48)	87 (5.17)	76.5 (10.0)	85.0 (16.1)	67.6 (21.4)	71.2 (17.6)	70.7 (19.9)	371.0 (69.6)	100 (7.86)	82.3 (12.4)	70.8 (21.6)	67.2 (26.2)	49.6 (8.34)	30.4 (7.39)	301.0 (66.5)
Total	1683	76.5 (10.9)	83.5 (18.7)	68.3 (22.8)	70.5 (18.3)	70.3 (21.4)	369.1 (76.6)	1272	83.2 (12.5)	72.8 (23.0)	69.8 (27.6)	50.2 (8.53)	31.3 (7.30)	307.3 (72.2)

VI = Vision Impairment, VA = Presenting Visual Acuity in the better-seeing eye, SD = Standard deviation

* VA for Grade 7 was the baseline VA whereas VA for Grade 9 was the endline VA.

Table 3. Linear regression model of potential predictors of total Grade 9 test score for middle school children in Anyang, China.

Variable	Simple regression adjusting for baseline test score only			Multiple regression*		
	Regression coefficient (95%CI)	Beta	P-value	Regression coefficient (95%CI)	Beta	P-value
Baseline Test score (Total)	.868 (.844, .892)	.869	<.001	.854 (.828, .880)	.854	<.001
Age (years)	-9.29 (-13.2, -5.43)	-.0581	<.001	-7.18 (-11.2, -3.19)	-.0445	<.001
Male sex	3.70 (.090, 7.31)	.0256	.045	2.39 (-1.25, 6.04)	.0166	.198
At least one parent with some college education	12.2 (8.46, 15.9)	.0801	<.001	8.04 (4.02, 12.1)	.0530	<.001
Above national average family income	4.58 (.940, 8.21)	.0305	.014	2.32 (-1.33, 5.96)	.0156	.212
Body mass index	.272 (-.215, .758)	.0136	.274	-	-	-
Waist circumference(cm)	-.017 (-.209, .174)	-.00220	.860	-	-	-
Time outdoors (hours/week)	-.934 (-1.40, -.467)	.0103	<.001	.044 (-.054, .142)	.0111	.375
Paediatric Quality of Life Score	-4.52 (-7.97, -1.08)	-.0326	.010	-3.68 (-7.12, -.244)	-.0266	.036
Spherical equivalent refractive error in better-seeing eye (Diopters)	.014 (-.875, .904)	.000411	.975	-	-	-
Presenting visual acuity in the better-seeing eye (logMAR)	-11.2 (-20.1, -2.34)	-.0309	.013	-12.6 (-21.5, -3.67)	-.0347	.006
Parental myopia						
None	Reference	Reference	Reference	Reference	Reference	Reference
Either	7.32 (3.04, 11.6)	.0421	.001	4.76 (.354, 9.16)	.0275	.034
Both	12.8 (5.62, 19.9)	.0441	<.001	8.19 (.713, 15.7)	.0283	.032
Child wearing glasses	3.46 (-.145, 7.07)	.0237	.060	-	-	-

* All variables with P<.05 in the simple regression adjusting for baseline score were included in the multiple regression.

CI=Confidence Interval