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ABSTRACT

Objectives To estimate the prevalence of poor vision in children aged 4-5 years and determine the impact of visual acuity on literacy.

Design Cross sectional study linking clinical, epidemiological and education data.

Setting Schools located in the city of Bradford, UK.

Participants Prevalence was determined for 11186 children participating in the Bradford school vision screening programme. Data linkage was undertaken for 5836 Born in Bradford (BiB) birth cohort study children participating both in the Bradford vision screening programme and the BiB Starting Schools Programme. 2025 children had complete data and were included in the multivariable analyses.

Main outcome measures Visual acuity was measured using a logMAR Crowded Test (higher scores = poorer visual acuity). Literacy measured by Woodcock Reading Mastery Tests-Revised (WRMT-R) subtest: Letter Identification (standardised).

Results The mean (SD) presenting visual acuity was 0.14 (0.09) logMAR (range 0.0 to 1.0). 9% of children had a presenting visual acuity worse than 0.2logMAR (failed vision screening), 4% worse than 0.3logMAR (poor visual acuity) and 2% worse than 0.4logMAR (visually impaired). Unadjusted analysis showed that the literacy score was associated with presenting visual acuity, reducing by 2.4 points for every 1 line (0.10logMAR) reduction in vision (95%CI -3.0 to -1.9). The association of presenting visual acuity with the literacy score remained significant after adjustment for demographic and socio-economic factors reducing by 1.7 points (95%CI -2.2 to -1.1) for every 1 line reduction in vision.

Conclusion Prevalence of decreased visual acuity was high compared to other population based studies. Decreased visual acuity at school entry is associated with reduced literacy. This may have important implications for the children's future educational, health and social outcomes.

Strengths and limitations of this study

- Data linkage provides a comprehensive data set which allowed adjustment for confounding factors.
- This is one of the first studies to investigate the impact of reduced vision on educational attainment.
- The study is based in a large multi-ethnic population
- The study is limited by its cross-sectional nature.
- Not all participants have complete data sets for all the variables.

INTRODUCTION

The United Kingdom National Screening Committee (UK NSC) recommends that vision screening should be provided to all children at age 4-5 years;[1] these recommendations form part of the Healthy Child Programme.[2] However the evidence supporting this recommendation is weak. In particular, there are limited data on the prevalence of vision levels in children at age 4-5 years when they enter Reception, and the effect of reduced vision on educational attainment in children has not yet been established.[3] Early literacy is a key indicator of future reading performance and educational attainment[4,5] which in turn affects long term health and social outcomes.[6,7] It is intuitive that poor vision will impact on a child's reading ability and lead to educational underachievement, yet there is little evidence to confirm this. Better evidence is therefore required to inform child screening policy both in the UK and internationally.

The aim of this study is to determine the prevalence of poor vision in a multi-ethnic population and explore the impact of reduced vision on developing literacy skills in young children as they commence primary school at age 4-5 years.

One of the challenges to the investigation of a causal relationship between vision and literacy is the potential confounding effect of socioeconomic factors. It is well known that socioeconomic deprivation is associated with poor levels of literacy; therefore any study seeking to explore the degree to which

poor vision affects literacy over and above effects of socioeconomic and other demographic factors requires comprehensive data collection.

The city of Bradford in the UK offers the opportunity to conduct such a study because it is the setting for the Born in Bradford (BiB) birth cohort study[8] which collected detailed epidemiological data during pregnancy, at birth and literacy measures in a sub-group of the children in their first year of school. Bradford also has a comprehensive vision screening programme which provides a detailed profile of children's vision. These data provide the unique opportunity to explore the association between visual acuity and early developing literacy with adjustment for the effects of potential confounding variables.

METHODS

Vision screening and literacy measures were prospectively collected from children in their first year of primary school within the same school term over two consecutive years (2012 - 2013 and 2013 - 2014). Vision screening data from all participants was used to determine the prevalence of poor vision. Baseline epidemiological data collected from mothers and children of the Born in Bradford cohort, literacy measures and data captured from the vision screening programme were linked in order to investigate the impact of vision on literacy. Details of each element are provided below. Ethics approval for the data linkage was granted by National Research Ethics Committee Yorkshire & the Humber- South Yorkshire (Ref 13/YH/0379).

Born in Bradford (BiB)

Born in Bradford (BiB) is a longitudinal multi-ethnic birth cohort study aiming to examine the impact of environmental, psychological and genetic factors on maternal and child health and wellbeing.[8] Bradford is a city with high levels of socio-economic deprivation and ethnic diversity. Approximately half of the births in the city are to mothers of South Asian origin. Women were recruited while waiting for a glucose tolerance test, routinely offered to all pregnant women registered at the Bradford Royal Infirmary at 26-28 weeks gestation. For those consenting, a baseline questionnaire was completed. The full BiB cohort recruited 12,453 women during 13,776 pregnancies between 2007 and 2010 and

the cohort is broadly representative of the city's maternal population.[8] Ethics approval for the data collection was granted by Bradford Research Ethics Committee (Ref 07/H1302/112).

Literacy

As part of a separate Born in Bradford "Starting Schools Programme" exploring literacy, movement and wellbeing, children's literacy levels on school entry were measured. All 123 Bradford primary schools were invited to participate, 76 separate schools agreed to take part and 2929 BiB children received a literacy assessment between September 2012 and July 2014.

Early literacy skills that predict future reading performance include letter identification.[4] Letter identification measures the child's ability to identify single letters, an essential skill mastered prior to reading. Letter identification was measured using the Woodcock Reading Mastery Tests-Revised (WRMT-R) subtest: Letter Identification, a validated reading skill test.[9]

In addition, a measure of acquired or receptive vocabulary was recorded using the British Picture Vocabulary Scale (BPVS).[10] It has been shown to be an important indicator of cognitive ability, providing a representation of the measure of IQ in young children. This measure is included to adjust for potential confounding due to levels of general cognitive ability.[10] All scores are standardised taking into account the child's age and time of testing during the academic year.

Vision

In Bradford there is an established vision screening programme for 4-5 year old school children, coverage is high (97%).[11] 11186 children from 123 primary schools across the city participated in the vision screening programme. 5836 BiB children were eligible for the study (started school between September 2012 and July 2014) and 4953 (85%) BiB children had completed the vision screening programme prior to the data linkage (Figure 1). The vision screening assessment includes standard protocols for measurement of distance visual acuity[12,13] right and left eyes, with spectacles if worn, cover test, ocular motility and non-cycloplegic auto refraction (Welch-Allyn Inc. Skaneateles. NY). Visual acuity was measured with the age appropriate recommended vision test[14], a LogMAR Crowded Test (Keeler, Windsor) the total score for each line represents 0.1 log unit. A matching card is used

and knowledge of letters is not necessary to perform the test.4834 children completed the vision screening and had visual acuity recorded for both right and left eyes (Figure 1). 118/4834 (2%) of children were unable to match letters, they were tested using Kay Pictures Crowded LogMAR (Kay pictures, Tring UK).[15,16] Refractive error is commonly associated with reduced visual acuity in young children,[17] non-cycloplegic autorefractor readings for the right and left eyes were recorded and a mean spherical equivalent (sphere plus half-negative cylinder) calculated for each eye of individual children.[17,18] 4578 out of 4834 children had a mean spherical equivalent calculated. Data from the vision screening programme used for the analyses includes presenting visual acuity (best visual acuity right or left eye, with glasses if worn) and the mean spherical equivalent from that same eye.

Presenting visual acuity will be referred to as visual acuity for the rest of the paper and in all tables. Visual acuity was categorised to examine prevalence of levels of vision. Four categories were established: better than 0.20 logMAR (a pass on visual screening), 0.225 to 0.30, 0.325 to 0.40, (referred to as "poor vision" in many published studies)[17,19] and worse than 0.4 (a category used to define visual impairment by the World Health Organisation).[20] Visual acuity was treated as a continuous variable in the statistical modelling allowing for letter by letter scoring.

Statistical analysis

Multi-level regression analysis (children nested within schools) was undertaken in BiB children where complete data sets from both the mother and child were available, 84 of 2109 children were excluded due to incomplete data (Figure 1). This was mainly due to incomplete data on the BPVS which was not recorded in 60 (3%) children. To analyse the effect of visual acuity on literacy, unadjusted analysis was undertaken on BiB children with complete data (n=2025). Subsequent adjustment for demographic and socioeconomic (maternal and child characteristics) including BPVS score to account for cognitive ability was then undertaken. The characteristics included in the statistical analysis were those found to be associated with both educational and visual outcomes in the current literature. Demographic factors were: ethnicity (determined by the mothers' ethnicity), sex at birth, birth weight, gestational age, language of baseline questionnaire completed by mother, mothers' place of birth. Socio-economic factors were: mother in receipt of benefits, level of mothers' education, mother smoked during pregnancy. [21-26] The characteristics are detailed in Table 1.

Table 1. Distribution of Characteristics in Born in Bradford (BiB) Children with Complete Data.

Characteristic	n (%)	
Letter ID score, mean (SD)	107.07 (12.5)	range 68 to 143
Visual Acuity (logMAR), mean (SD)	0.13 (0.09)	range 0.0 to 0.8
British Picture Vocabulary Score, mean (SD)	100.97 (14.47)	range 39 to 160
Mean Spherical Equivalent (D), mean (SD)*	1.07 (0.64)	range -2 to +9.5
****Ethnicity**		
White British	671 (33.2)	
Pakistani	1106 (54.6)	
Other	248 (12.2)	
Sex at birth (M:F)	1010:1015	
Birth weight (g), mean (SD)	3191 (541)	range 680 to 5180
Gestational age (weeks), mean (SD)	39.14 (1.63)	range 27 to 43
****Baseline Questionnaire Language**		
English	1541 (76)	
Other language	484 (24)	
****UK born mother**		
Yes	1177 (58)	
No	848 (42)	
****Receiving Benefits**		
Yes	880 (43.46)	
No	1145 (56.54)	
****Mothers Level of Education**		
Low (<5 GCSE equivalent & unknown)	567 (28)	
Medium (5 GCSE & A level equivalent)	1050 (52)	
High (higher than A-level)	408 (20)	
****Mother Smoked in pregnancy**		
Yes	282 (14)	
No	1743 (86)	

D = dioptres
*n=1893 all other variables n=2025
**Determined by mothers' response to the baseline questionnaire.

The regression analyses were undertaken in three steps; firstly demographic factors (listed above) were included in the model, a second model was then run adjusting for the socio-economic factors (listed above) and finally a fully adjusted model was run adjusting for all demographic and socioeconomic factors and the BPVS score for general cognitive ability. In all these models 2025 children from 74 schools were included.

Further regression analysis was undertaken to examine the impact of mean spherical equivalent on a subsample with complete data available (n=1893). A sensitivity analysis was also undertaken excluding children unable to carry out letter matching (n=1979). Multi-level analysis was undertaken in order to account for variability between schools; the variance in attainment attributed to differences

between schools was calculated to provide a variance partition coefficient for each model. All analyses were carried out using Stata 13 (StataCorp, College Station, TX).

RESULTS

The overall mean (SD) visual acuity for all children (n=11186) who received vision screening was 0.14 (0.09) logMAR (range 0.0 to 1.0). 8.7% (977/11186) of children had a visual acuity worse than 0.2logMAR, 4% (475/11186) worse than 0.3logMAR and 1.8% (206/11186) of children demonstrated a visual acuity of worse than 0.4logMAR. There was no clinically significant difference between the BiB and non-BiB children (supplementary Table S1).

The univariate and adjusted model analyses for the BiB children are shown in Table 2. Unadjusted analysis of the BiB children (n=2025) showed that the literacy score was associated with the level of visual acuity. The literacy score reduced by 2.42 points for every 1 line (0.10logMAR) reduction in visual acuity (95% CI -2.98 to -1.87) p<0.001. When adjusted to account for cognitive ability (BPVS), demographic factors or socio-economic factors the impact of visual acuity remained significant and continued to remain statistically significant in the multivariable model after all factors are accounted for with the literacy score reducing by 1.65 (95% CI -2.17 to -1.13) p<0.001 for every 1 line (0.10logMAR) reduction in visual acuity . The association between visual acuity and literacy remained after a sensitivity analysis was undertaken to investigate the effect of poor literacy by excluding children unable to carry out the letter matching (supplementary Table S2). Adjustment for mean spherical equivalent made no material difference and by itself was not associated with literacy (p=0.164) it therefore was not included in the model. The variance in attainment attributed to the difference between schools was 9% in the unadjusted model and 12% in the fully adjusted model across 74 schools.

Table 2. Associations between Literacy (Letter Identification Score) and Visual Acuity, British Picture Vocabulary Scale (BPVS), Socio-economic and Demographic (child and maternal) factors n=2025 children n= 74 schools.

FACTOR	UNADJUSTED mean difference in literacy scores (95% CI)	ADJUSTED BPVS mean difference in literacy scores (95% CI)	ADJUSTED DEMOGRAPHIC mean difference in literacy scores (95% CI) *	ADJUSTED SOCIOECONOMIC mean difference in literacy scores (95% CI) **	FULLY ADJUSTED MODEL mean difference in literacy scores (95% CI) ***
change in literacy score per 1 line (0.1log unit) of Visual Acuity	-2.42 (-2.98 to -1.87) p<0.001	-1.79 (-2.32 to -1.26) p<0.001	-1.72 (-2.24 to -1.19) p<0.001	-1.72 (-2.25 to -1.19) p<0.001	-1.65 (-2.17 to -1.13) p<0.001
change in literacy score per 1 unit change in BPVS		0.27 (0.23 to 0.30) p<0.001	0.26 (0.22 to 0.30) p<0.001	0.25 (0.22 to 0.29) p<0.001	0.25 (0.21 to 0 .28) p<0.001
Ethnicity					
White British			reference		reference
Pakistani			0.83 (-0.82 to 2.47) p=0.325		-0.14 (-1.86 to 1.58) p= 0.872
Other			3.79 (1.86 to 5.73) p<0.001		2.85 (0.88 to 4.82) p=0.005
Sex at birth					
Male			reference		reference
Female			3.01 (2.03 to 3.99) p<0.001		3.06 (2.09 to 4.04) p<0.001
Birth weight (g)			0.001 (0.0001 to 0.002) p=0.028		0.001 (0.0001 to 0.002) p=0.036
Gestational age (weeks)			0.006 (-0.35 to 0.37) p=0.975		-0.01 (-0.37 to 0.34) p=0.937
Questionnaire Language					
English			1.78 (0.21 to 3.35) p=0.026		1.61 (3.18 to 0.04) p=0.045
Other language			reference		reference
UK born					
Yes			-1.19 (-2.66 to 0.28) p=0.113		-0.97(-0.49 to 2.43) p=0.192
No			reference		reference
Receiving Benefits					
Yes				-1.05 (-2.06 to 0.03) p=0.043	-1.03 (-2.04 to -0.03) p=0.045
No				reference	reference
Level of Education					
Low (<5 GCSE equivalent & unknown)				reference	reference
Medium (5 GCSE & A level equivalent)				1.14 (-0.024 to 2.3) p=0.055	1.13 (-0.04 to 2.3) p=0.059
High (higher than A-level)				3.30 (1.8 to 4.8) p<0.001	3.20 (1.71 to 4.70) p<0.001
Smoked in pregnancy					
Yes				-2.19 (-3.68 to -0.69) p=0.004	-1.82 (0.25 to 3.39) p=0.023
No				reference	reference

*Demographic adjustment includes; Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth.
**Socioeconomic adjustment includes; Visual Acuity, BPVS, receipt of benefits, level of mothers' education, mother smoked during pregnancy.
***Fully adjusted analysis includes all factors Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth, receipt of benefits, level of mothers education ,mother smoked during pregnancy

DISCUSSION

This study is the first to reliably demonstrate that poor visual acuity in young children is associated with reduced early developing literacy. Our findings indicate a high proportion of children (9%) had reduced visual acuity with 2% classified as visually impaired.[20] This is likely to impact significantly on their early developing literacy. The Bradford cohort of children demonstrates a higher prevalence of poor presenting visual acuity (defined as worse than 0.3 logMAR) compared to that reported elsewhere.[17,19,21] (Table 3).

Table 3.Comparison of studies reporting prevalence of poor visual acuity (worse than 0.30logMAR)

Author	Community	Age (years)	No. of participants	Prevalence (%)
Robaei D, Rose K, Ojaimi E, et al.[17]	Australia	6-7	1738	0.9
Friedman DS, Repka MX, Katz J, et al.[19]	USA	2.5-5.5	1714	1.5
Williams C, Northstone K, Howard M, et al.[21]	Bristol, UK	7	7825	0.6
Bruce A, Fairley L, Chambers B, et al	Bradford, UK	4-5	11186	4.0

For the majority of children in Bradford, vision screening at school entry is their first assessment of visual status; this is likely to account for the increased prevalence observed. In this study 2% of children were wearing glasses at vision screening, similar to that found in an urban population of children aged 30 to 71 months in the US (1.7%),[19] but substantially lower than the 4.4% of 6-year-old children in Australia.[17] Another UK cohort study[21] reported 0.6% prevalence of poor presenting visual acuity at the age of 7 years; however 3% of the children in their sample had undergone previous treatment. The prevalence reported in the US study was 1.2% in White children and 1.8% in Black children.[19] In our study 2.7% of White British, 5.2% of Pakistani children and 2.8% of other ethnicities had VA worse than 0.3 logMAR. In both studies the differences in visual acuity between the ethnic groups was not statistically significant.

It has been shown that children from socio-economically deprived households have an increased prevalence of vision problems,[27, 28] which may in part be due to inequality in accessing health services.[29] The Bradford vision screening programme covers 97% of children[11] and therefore does not exclude children from the lower socioeconomic areas. The high levels of deprivation in the city may help explain the higher prevalence level of poor visual acuity. Educational attainment is multifactorial

and influenced by social disadvantage and demographic factors, differences manifest early and are demonstrable through gaps in literacy achievement.[25,26] Factors known to be associated with educational outcome such as socioeconomic status,[26,30] gender,[31] and mothers' education[32] were also shown in this study to impact on literacy (Table 2). There was no difference between the literacy scores of the White British and the Pakistani children however there was a positive association between literacy and visual acuity for children in the "other" ethnic category. A third of children in this category had mothers with high educational attainment and this may help explain the association. The association between the level of visual acuity and literacy remains significant after adjustment for socio-economic and demographic factors (Table 2).

A small number of population based studies have examined the impact of visual acuity on educational outcome. A US study evaluating the effect of visual function on academic performance (children aged 6-9 years) found no association. However, the key indicator of academic performance (Metropolitan Readiness Test) was not available for a large proportion of the children and a proxy measure of attainment was used, neither did the study take into account the effects of potential confounding factors.[33] Retrospective analysis of the 1958 British birth cohort reporting outcomes at age 11 years found no association between unilateral amblyopia and educational, health and social outcomes, however, participants with bilateral visual loss were excluded from the study.[34] A large cohort study in Singapore reported no effect of presenting visual acuity on academic school performance[35] but the Singapore cohort of children at age 9 – 10 years only included a small number of children with poor vision which reduced the power of the study to detect any significant association.

Our paper reports the largest population based study which explores the impact of visual acuity on literacy and has a number of strengths. The cohort is set in a multi-ethnic population and the use of data linkage has allowed us to undertake rigorous analysis taking into account the effect of potential confounding factors. However, there are limitations, 2929 out of 5836 (50%) of BiB children had received a literacy test at the time of data linkage; this reduced the number of children (n= 2025) who had complete data sets and may compromise the representativeness of the sample. However, comparison of the Born in Bradford children (n=2025) with complete data demonstrated a similar percentage of children within each quintile of the Index of Multiple Deprivation and is comparable to the complete BiB cohort of children (n=13773).[8] The prevalence of poor vision in this cohort of

children (n=2025) is also similar to all Bradford children (n=11186) (Table S1). As a proxy indicator for English as a second language we used the language in which the baseline questionnaire was completed by the mother during pregnancy. Although all children are taught in school in English this may not be the primary language of choice at home; this information was not available.

The study has the inherent limitations of a cross sectional design, which reduces our ability confidently to infer causality. However, it is unlikely that poor literacy resulted in poor performance in the vision test; the majority of children (98%) performed the recommended age appropriate vision test and the association between vision and literacy remained after excluding children unable to accomplish the letter matching. In addition, if indeed poor literacy causes poor vision we would expect that those children with specific reading difficulties (dyslexia) would demonstrate reduced visual acuity, in a recent study 4 out of 5 children with reading difficulties demonstrated normal visual function.[36]

By linking the clinical data set from the population based vision screening programme with epidemiological data from a large birth cohort study, along with the baseline literacy assessments, this is the first multi-ethnic population based study to have the statistical power to take into account the multiple factors that are known to impact on educational outcomes. Our results demonstrate a significant association between visual acuity and early literacy. In a population with a high prevalence of reduced vision this has important implications for children's future educational outcomes. The reduction in the literacy score by around 2% for every line of vision reduction is important in a population where there are poor levels of vision on school entry. At a time of change and uncertainty in the commissioning of vision screening services[37,38] it is important to understand both the level of vision in the population and the impact this is likely to have on future health and social outcomes. This study strengthens the argument for a national vision screening programme. The impact of such a programme will depend on the degree to which detection of reduced vision at age 4-5 years results in effective intervention to improve vision and the impact this has on health, educational and social outcomes. Further research is required to determine the extent to which children with poor vision access treatment and the impact of such treatment not only on levels of vision but also on their educational attainment.

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Contributors AB initiated the project, designed data collection, monitored data collection for the whole study, wrote the statistical analysis plan, cleaned and analysed the data, and drafted and revised the paper. She is guarantor. LF wrote the statistical analysis plan, cleaned the data and revised the draft paper. BC and JW initiated the project and revised the draft paper. TS initiated the project, wrote the statistical analysis plan and revised the draft paper.

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No additional data is available

Competing Interests None declared

Ethics approval National Research Ethics Committee Yorkshire & the Humber- South Yorkshire (Ref 13/YH/0379).

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Legend Figure 1

Figure1. Flow chart of data linked between Bradford Vision screening programme, Starting Schools and Born in Bradford participants. BiB = Born in Bradford.

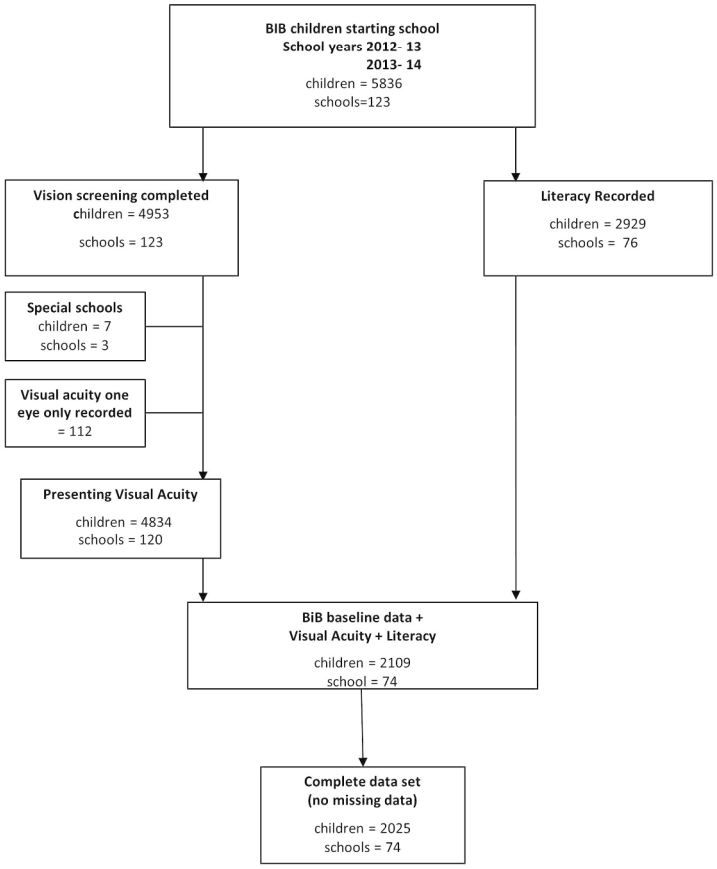

Figure1. Flow chart of data linked between Bradford Vision screening programme, Starting Schools and Born in Bradford participants. BiB = Born in Bradford.

190x274mm (284 x 284 DPI)

Table S1. Comparison of Born in Bradford (BiB) Children with Non-Born in Bradford Children.

Characteristic	**All children** mean (SD) (range)	**Non-BiB children** mean (SD)	**BiB children** mean (SD)	**Mean Difference (95% CI)**
Letter ID score	105.64 (12.78) (68-143) n=6249	104.7 (12.98) n=3320	106.7 (12.46) n=2929	-1.99 (-2.62 to -1.36)
British Picture Vocabulary Score	99.03 (16.43) (39 to 161) n=6160	97.96 (17.55) n=3268	100.23 (14.97) n=2892	-2.28 (-3.09 to -1.46)
Visual Acuity (logMAR)	0.137 (0.09) (0 to 1.0) n= 12083	0.139 (0.09) n=7215	0.134 (0.09) n=4868	0.005 (0.002 to 0.008)
Mean Spherical Error (Dioptres)	1.05 (0.69) (-5.6 to +9.74) n=11483	1.04 (0.71) n=6871	1.06 (0.67) n=4612	0.02 (-0.046 to 0.005)

Table S2. Associations between Literacy (Letter Identification Score) and Visual Acuity, British Picture Vocabulary Scale (BPVS), Socio-economic and demographic (child and maternal) factors n=1979 children n= 74 school

FACTOR	UNADJUSTED mean difference in literacy scores (95% CI)	ADJUSTED BPVS mean difference in literacy scores (95% CI)	ADJUSTED DEMOGRAPHIC mean difference in literacy scores (95% CI) *	ADJUSTED SOCIOECONOMIC mean difference in literacy scores (95% CI) **	FULLY ADJUSTED MODEL mean difference in literacy scores (95% CI) ***
change in literacy score per 1 line (0.1log unit) of Visual Acuity	-2.41 (-2.97 to -1.85) p<0.001	-1.83 (-2.37 to -1.29) p<0.001	-1.76 (-2.29 to -1.23) p<0.001	-1.76 (-2.29 to -1.23) p<0.001	-1.69 (-2.21 to -1.16) p<0.001
change in literacy score per 1 unit change in BPVS		0.26 (0.23 to 0.30) p<0.001	0.26 (0.22 to 0.30) p<0.001	0.25 (0.22 to 0.29) p<0.001	0.24 (0.21 to 0 .28) p<0.001
Ethnicity					
White British			reference		reference
Pakistani			1.08 (-0.56 to 2.72) p=0.196		0.10 (-1.6 to 1.8) p= 0.91
Other			3.78 (1.84 to 5.73) p<0.001		2.86 (0.88 to 4.84) p=0.005
Sex at birth					
Male			reference		reference
Female			2.8 (1.82 to 3.79) p<0.001		2.86 (1.88 to 3.84) p<0.001
Birth weight (g)			0.001 (0.0003 to 0.003) p=0.015		0.001 (0.0002 to 0.002) p=0.021
Gestational age (weeks)			0.046 (-0.32 to 0.41) p=0.806		0.027 (-0.33 to 0.39) p=0.883
Questionnaire Language					
English			1.94 (0.35 to 3.52) p=0.016		1.8 (0.22 to 3.4) p=0.026
Other language			reference		reference
UK born					
Yes			1.33 (-0.15 to 2.81) p=0.077		1.12 (-0.35 to 2.59) p=0.14
No			reference		reference
Receiving Benefits					
Yes				-0.98 (-2.01 to 0.05) p=0.062	-0.96 (-1.97 to 0.05) p=0.063
No				reference	reference
Level of Education					
Low (<5 GCSE equivalent & unknown)				reference	reference
Medium (5 GCSE & A level equivalent)				0.99 (-0.19 to 2.16) p=0.099	0.96 (-0.22 to 2.15) p=0.11
High (higher than A-level)				3.00 (1.46 to 4.50) p<0.001	2.91 (1.4 to 4.41) p<0.001
Smoked in pregnancy					
Yes				-2.38 (-3.87 to -0.88) p=0.002	-1.94 (-3.5 to -0.36) p=0.016
No				reference	reference

*Demographic adjustment includes; Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mother place of birth.
**Socioeconomic adjustment includes; Visual Acuity, BPVS, receipt of benefits, level of mothers' education, mother smoked during pregnancy.
***Fully adjusted analysis includes all factors Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth, receipt of benefits, level of mothers education ,mother smoked during pregnancy.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p2.
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p3. & p4.
Objectives	3	State specific objectives, including any prespecified hypotheses	P3.
Methods			
Study design	4	Present key elements of study design early in the paper	p4. & p5.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p4. p5. & p6.
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	p4. p5. & p6.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p4. p5. & p6.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p4. p5. p6. and Table 1
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	p4. p5. p6. and Figure 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p6. & p7.
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p6. & p7.
		(*b*) Describe any methods used to examine subgroups and interactions	p7.
		(*c*) Explain how missing data were addressed	p6. & p7.
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	p7.

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Figure 1 & p6
		(b) Give reasons for non-participation at each stage	Figure 1 & p6
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1 & Supplementary Table S1
		(b) Indicate number of participants with missing data for each variable of interest	Figure 1
Outcome data	15*	Report numbers of outcome events or summary measures	p8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	p8 & Table 2
		(*b*) Report category boundaries when continuous variables were categorized	p6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	p8 & supplementary Table S2
Discussion			
Key results	18	Summarise key results with reference to study objectives	p10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p11 & p12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p10,p11,p12 & Table 3
Generalisability	21	Discuss the generalisability (external validity) of the study results	p12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p13

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The Impact of Visual Acuity on Developing Literacy at age 4-5 years: a cohort nested cross sectional study

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The Impact of Visual Acuity on Developing Literacy at age 4-5 years: a cohort nested cross sectional study.

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The Impact of Visual Acuity on Developing Literacy at age 4-5 years: a cohort nested cross sectional study.

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ABSTRACT

Objectives To estimate the prevalence of poor vision in children aged 4-5 years and determine the impact of visual acuity on literacy.

Design Cross sectional study linking clinical, epidemiological and education data.

Setting Schools located in the city of Bradford, UK.

Participants Prevalence was determined for 11186 children participating in the Bradford school vision screening programme. Data linkage was undertaken for 5836 Born in Bradford (BiB) birth cohort study children participating both in the Bradford vision screening programme and the BiB Starting Schools Programme. 2025 children had complete data and were included in the multivariable analyses.

Main outcome measures Visual acuity was measured using a logMAR Crowded Test (higher scores = poorer visual acuity). Literacy measured by Woodcock Reading Mastery Tests-Revised (WRMT-R) subtest: Letter Identification (standardised).

Results The mean (SD) presenting visual acuity was 0.14 (0.09) logMAR (range 0.0 to 1.0). 9% of children had a presenting visual acuity worse than 0.2logMAR (failed vision screening), 4% worse than 0.3logMAR (poor visual acuity) and 2% worse than 0.4logMAR (visually impaired). Unadjusted analysis showed that the literacy score was associated with presenting visual acuity, reducing by 2.4 points for every 1 line (0.10logMAR) reduction in vision (95%CI -3.0 to -1.9). The association of presenting visual acuity with the literacy score remained significant after adjustment for demographic and socio-economic factors reducing by 1.7 points (95%CI -2.2 to -1.1) for every 1 line reduction in vision.

Conclusion Prevalence of decreased visual acuity was high compared to other population based studies. Decreased visual acuity at school entry is associated with reduced literacy. This may have important implications for the children's future educational, health and social outcomes.

Strengths and limitations of this study

- Data linkage provides a comprehensive data set which allowed adjustment for confounding factors.
- This is one of the first studies to investigate the impact of reduced vision on educational attainment.
- The study is based in a large multi-ethnic population
- The study is limited by its cross-sectional nature.
- Not all participants have complete data sets for all the variables.

INTRODUCTION

The United Kingdom National Screening Committee (UK NSC) recommends that vision screening should be provided to all children at age 4-5 years;[1] these recommendations form part of the Healthy Child Programme.[2] However the evidence supporting this recommendation is weak. In particular, there are limited data on the prevalence of vision levels in children at age 4-5 years when they first enter school, and the effect of reduced vision on educational attainment in children has not yet been established.[1, 3] Early literacy is a key indicator of future reading performance and educational attainment[4 ,5] which in turn affects long term health and social outcomes.[6 ,7] It is intuitive that poor vision will impact on a child's reading ability and lead to educational underachievement, yet there is little evidence to confirm this. At a time of change and uncertainty in the commissioning of vision screening services it is important to understand both the level of vision in the population and the impact this is likely to have on future health and social outcomes.[8 ,9] Better evidence is therefore required to inform child screening policy both in the UK and internationally.

The aim of this study is to determine the prevalence of poor vision in a multi-ethnic population and explore the impact of reduced vision on developing literacy skills in young children as they commence primary school at age 4-5 years.

One of the challenges to the investigation of a causal relationship between vision and literacy is the potential confounding effect of socioeconomic factors. It is well known that socioeconomic deprivation

is associated with poor levels of literacy; therefore any study seeking to explore the degree to which poor vision affects literacy over and above effects of socioeconomic and other demographic factors requires comprehensive data collection.

The city of Bradford in the UK offers the opportunity to conduct such a study because it is the setting for the Born in Bradford (BiB) birth cohort study[10] which collected detailed epidemiological data during pregnancy, at birth and literacy measures in a sub-group of the children in their first year of school. Bradford also has a comprehensive vision screening programme which provides a detailed profile of children's vision. These data provide the unique opportunity to explore the association between visual acuity and early developing literacy with adjustment for the effects of potential confounding variables.

METHODS

Vision screening and literacy measures were prospectively collected from children in their first year of primary school within the same school term over two consecutive years (2012 - 2013 and 2013 - 2014). Vision screening data from all participants was used to determine the prevalence of poor vision. Baseline epidemiological data collected from mothers and children of the Born in Bradford cohort, literacy measures and data captured from the vision screening programme were linked in order to investigate the impact of vision on literacy. Details of each element are provided below. Ethics approval for the data linkage was granted by National Research Ethics Committee Yorkshire & the Humber- South Yorkshire (Ref 13/YH/0379).

Born in Bradford (BiB)

Born in Bradford (BiB) is a longitudinal multi-ethnic birth cohort study aiming to examine the impact of environmental, psychological and genetic factors on maternal and child health and wellbeing.[10] Bradford is a city with high levels of socio-economic deprivation and ethnic diversity. Approximately half of the births in the city are to mothers of South Asian origin. Women were recruited while waiting for a glucose tolerance test, routinely offered to all pregnant women registered at the Bradford Royal Infirmary at 26-28 weeks gestation. For those consenting, a baseline questionnaire was completed. The full BiB cohort recruited 12,453 women during 13,776 pregnancies between 2007 and 2010 and

the cohort is broadly representative of the city's maternal population.[10] Ethics approval for the data collection was granted by Bradford Research Ethics Committee (Ref 07/H1302/112).

Literacy

As part of a separate Born in Bradford "Starting Schools Programme" exploring literacy, movement and wellbeing, children's literacy levels on school entry were measured in school by experienced research assistants. All 123 Bradford primary schools were invited to participate, 76 separate schools agreed to take part and 2929 BiB children received a literacy assessment between September 2012 and July 2014.

Early literacy skills that predict future reading performance include letter identification.[4] Letter identification measures the child's ability to identify single letters, an essential skill mastered prior to reading and one of the best predictors of reading acheivement.[11] Letter identification was measured using the Woodcock Reading Mastery Tests-Revised (WRMT-R) subtest: Letter Identification, a validated reading skill test.[12]

In addition, a measure of acquired or receptive vocabulary was recorded using the British Picture Vocabulary Scale (BPVS).[13] It has been shown to be an important indicator of cognitive ability, providing a representation of the measure of IQ in young children. This measure is included to adjust for potential confounding due to levels of general cognitive ability.

Both measures are standardised taking into account the child's age and time of testing during the academic year, a mean score of 100 would be expected for a given population.[12, 13]

Vision

A vision screening programme for 4-5 year old school children has been established in Bradford. The screening programme is conducted in school by orthoptists. Due to the nature of the programme being conducted after school entry coverage is high at 97%.[14] 11186 children from 123 primary schools across the city participated in the vision screening programme. 5836 BiB children were eligible for the study (started school between September 2012 and July 2014) and 4953 (85%) BiB children had completed the vision screening programme prior to the data linkage (Figure 1). The vision screening assessment includes standard protocols for measurement of distance visual acuity[15]

[16] right and left eyes, with spectacles if worn. The visual acuity test was administered by orthoptists, performed at a distance of three metres and visual acuity was measured to threshold (i.e. best achievable visual acuity). Additional tests carried out by the orthoptists were cover test, ocular motility and non-cycloplegic auto refraction (Welch-Allyn Inc. Skaneateles. NY). Visual acuity was measured with an age appropriate LogMAR Crowded Test (Keeler, Windsor)[15] which has four letters per line each letter having a score of 0.025; the total score for each line represents 0.1 log unit. A matching card is used and knowledge of letters is not necessary to perform the test. 4834 children completed the vision screening and had visual acuity recorded for both right and left eyes (Figure 1). 118/4834 (2%) of children were unable to match letters, they were tested using Kay Pictures Crowded LogMAR (Kay pictures, Tring UK).[17,18] Refractive error is commonly associated with reduced visual acuity in young children,[19] hence non-cycloplegic autorefractor readings for the right and left eyes were recorded and a mean spherical equivalent (sphere plus half-negative cylinder) calculated for each eye of individual children.[19,20] 4578 out of 4834 children had a mean spherical equivalent calculated. Data from the vision screening programme used for the analyses includes presenting visual acuity (best visual acuity right or left eye, with glasses if worn) and the mean spherical equivalent from that same eye.

Presenting visual acuity will be referred to as visual acuity for the rest of the paper and in all tables. Visual acuity was categorised to examine prevalence of levels of vision. Four categories were established: better than 0.20 logMAR (a pass on visual screening), 0.225 to 0.30, 0.325 to 0.40, (referred to as “poor vision” in many published studies)[19,21] and worse than 0.4 (a category used to define visual impairment by the World Health Organisation).[22] Visual acuity was treated as a continuous variable in the statistical modelling allowing for letter by letter scoring.

Statistical analysis

Multi-level regression analysis (children nested within schools) was undertaken in BiB children where complete data sets from both the mother and child were available, 84 of 2109 children were excluded due to incomplete data (Figure 1). This was mainly due to incomplete data on the BPVS which was not recorded in 60 (3%) children. To analyse the effect of visual acuity on literacy, unadjusted analysis was undertaken on BiB children with complete data (n=2025). Subsequent adjustment for

demographic and socioeconomic (maternal and child characteristics) including BPVS score to account for cognitive ability was then undertaken. The characteristics included in the statistical analysis were those found to be associated with both educational and visual outcomes in the current literature. Demographic factors were: ethnicity (determined by the mothers' ethnicity), sex at birth, birth weight, gestational age, language of baseline questionnaire completed by mother, mothers' place of birth. Socio-economic factors were: mother in receipt of benefits, level of mothers' education, mother smoked during pregnancy. [23-28] The characteristics are detailed in Table 1.

Table 1. Distribution of Characteristics in Born in Bradford (BiB) Children with Complete Data.

Characteristic	Mean (SD)	
Letter ID score	107.07 (12.5)	range 68 to 143
Visual Acuity (logMAR)	0.13 (0.09)	range 0.0 to 0.8
British Picture Vocabulary Score	100.97 (14.47)	range 39 to 160
Mean Spherical Equivalent* (D)	1.07 (0.64)	range -2 to +9.5
Birth weight (g)	3191 (541)	range 680 to 5180
Gestational age (weeks)	39.14 (1.63)	range 27 to 43
Sex at birth (M:F)	1010:1015	
Ethnicity**	**n (%)**	
White British	671 (33.2)	
Pakistani	1106 (54.6)	
Other	248 (12.2)	
Baseline Questionnaire Language**	**n (%)**	
English	1541 (76)	
Other language	484 (24)	
UK born mother**	**n (%)**	
Yes	1177 (58)	
No	848 (42)	
Receiving Benefits**	**n (%)**	
Yes	880 (43.46)	
No	1145 (56.54)	
Mothers Level of Education**	**n (%)**	
Low (<5 GCSE equivalent & unknown)	567 (28)	
Medium (5 GCSE & A level equivalent)	1050 (52)	
High (higher than A-level)	408 (20)	
Mother Smoked in pregnancy**	**n (%)**	
Yes	282 (14)	
No	1743 (86)	

D = dioptres
*n=1893 all other variables n=2025
**Determined by mothers' response to the baseline questionnaire.

The regression analyses were undertaken in three steps; firstly demographic factors (listed above) were included in the model, a second model was then run adjusting for the socio-economic factors (listed above) and finally a fully adjusted model was run adjusting for all demographic and socioeconomic factors and the BPVS score for general cognitive ability. In all these models 2025 children from 74 schools were included.

Further regression analysis was undertaken to examine the impact of mean spherical equivalent on a subsample with complete data available (n=1893). A sensitivity analysis was also undertaken excluding children unable to carry out letter matching (n=1979). Multi-level analysis was undertaken

in order to account for variability between schools; the variance in attainment attributed to differences between schools was calculated to provide a variance partition coefficient for each model. All analyses were carried out using Stata 13 (StataCorp, College Station, TX).

RESULTS

The overall mean (SD) visual acuity for all children (n=11186) who received vision screening was 0.14 (0.09) logMAR (range 0.0 to 1.0). 8.7% (977/11186) of children had a visual acuity worse than 0.2logMAR, 4% (475/11186) worse than 0.3logMAR and 1.8% (206/11186) of children demonstrated a visual acuity of worse than 0.4logMAR. There was no clinically significant difference between the BiB and non-BiB children (supplementary Table S1).

The univariate and adjusted model analyses for the BiB children are shown in Table 2. Unadjusted analysis of the BiB children (n=2025) showed that the literacy score was associated with the level of visual acuity. The literacy score reduced by 2.42 points for every 1 line (0.10logMAR) reduction in visual acuity (95% CI -2.98 to -1.87) p<0.001. When adjusted to account for cognitive ability (BPVS), demographic factors or socio-economic factors the impact of visual acuity remained significant and continued to remain statistically significant in the multivariable model after all factors are accounted for with the literacy score reducing by 1.65 (95% CI -2.17 to -1.13) p<0.001 for every 1 line (0.10logMAR) reduction in visual acuity . The association between visual acuity and literacy remained after a sensitivity analysis was undertaken to investigate the effect of poor literacy by excluding children unable to carry out the letter matching (supplementary Table S2). Adjustment for mean spherical equivalent made no material difference and by itself was not associated with literacy (p=0.164) it therefore was not included in the model. The variance in attainment attributed to the difference between schools was 9% in the unadjusted model and 12% in the fully adjusted model across 74 schools.

Table 2. Associations between Literacy (Letter Identification Score) and Visual Acuity, British Picture Vocabulary Scale (BPVS), Socio-economic and Demographic (child and maternal) factors n=2025 children n= 74 schools.

FACTOR	UNADJUSTED mean difference in literacy scores (95% CI)	ADJUSTED BPVS mean difference in literacy scores (95% CI)	ADJUSTED DEMOGRAPHIC mean difference in literacy scores (95% CI) *	ADJUSTED SOCIOECONOMIC mean difference in literacy scores (95% CI) **	FULLY ADJUSTED MODEL mean difference in literacy scores (95% CI) ***
change in literacy score per 1 line (0.1log unit) of Visual Acuity	-2.42 (-2.98 to -1.87) p<0.001	-1.79 (-2.32 to -1.26) p<0.001	-1.72 (-2.24 to -1.19) p<0.001	-1.72 (-2.25 to -1.19) p<0.001	-1.65 (-2.17 to -1.13) p<0.001
change in literacy score per 1 unit change in BPVS		0.27 (0.23 to 0.30) p<0.001	0.26 (0.22 to 0.30) p<0.001	0.25 (0.22 to 0.29) p<0.001	0.25 (0.21 to 0 .28) p<0.001
Ethnicity					
White British			reference		reference
Pakistani			0.83 (-0.82 to 2.47) p=0.325		-0.14 (-1.86 to 1.58) p= 0.872
Other			3.79 (1.86 to 5.73) p<0.001		2.85 (0.88 to 4.82) p=0.005
Sex at birth					
Male			reference		reference
Female			3.01 (2.03 to 3.99) p<0.001		3.06 (2.09 to 4.04) p<0.001
Birth weight (g)			0.001 (0.0001 to 0.002) p=0.028		0.001 (0.0001 to 0.002) p=0.036
Gestational age (weeks)			0.006 (-0.35 to 0.37) p=0.975		-0.01 (-0.37 to 0.34) p=0.937
Questionnaire Language					
English			1.78 (0.21 to 3.35) p=0.026		1.61 (3.18 to 0.04) p=0.045
Other language			reference		reference
UK born					
Yes			-1.19 (-2.66 to 0.28) p=0.113		-0.97(-0.49 to 2.43) p=0.192
No			reference		reference
Receiving Benefits					
Yes				-1.05 (-2.06 to 0.03) p=0.043	-1.03 (-2.04 to -0.03) p=0.045
No				reference	reference
Level of Education					
Low (<5 GCSE equivalent & unknown)				reference	reference
Medium (5 GCSE & A level equivalent)				1.14 (-0.024 to 2.3) p=0.055	1.13 (-0.04 to 2.3) p=0.059
High (higher than A-level)				3.30 (1.8 to 4.8) p<0.001	3.20 (1.71 to 4.70) p<0.001
Smoked in pregnancy					
Yes				-2.19 (-3.68 to -0.69) p=0.004	-1.82 (0.25 to 3.39) p=0.023
No				reference	reference

*Demographic adjustment includes; Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth.
**Socioeconomic adjustment includes; Visual Acuity, BPVS, receipt of benefits, level of mothers' education, mother smoked during pregnancy.
***Fully adjusted analysis includes all factors Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth, receipt of benefits, level of mothers education ,mother smoked during pregnancy

DISCUSSION

This study is the first to reliably demonstrate that poor visual acuity in young children is associated with reduced early developing literacy. The mean visual acuity (Table 1) of these 4 -5 year old children is similar to previously published normative data,[29] however, our findings indicate a high proportion of children (9%) had reduced visual acuity with 2% classified as visually impaired.[22] This is likely to impact significantly on their early developing literacy. The Bradford cohort of children demonstrates a higher prevalence of poor presenting visual acuity (defined as worse than 0.3 logMAR) compared to that reported elsewhere.[19,21,23,30] (Table 3).

Table 3.Comparison of studies reporting prevalence of poor visual acuity (worse than 0.30logMAR)

Author	Community	Age (years)	No. of participants	Prevalence (%)
Robaei D, Rose K, Ojaimi E, et al.[19]	Australia	6-7	1738	0.9
Friedman DS, Repka MX, Katz J, et al.[21]	USA	2.5-5.5	1714	1.5
Williams C, Northstone K, Howard M, et al.[23]	Bristol, UK	7	7825	0.6
O'Donoghue L, McClelland JF, Logan NS et al[30]	Northern Ireland, UK	6-7	392	1.5
Bruce A, Fairley L, Chambers B, et al	Bradford, UK	4-5	11186	4.0

For the majority of children in Bradford, vision screening at school entry is their first assessment of visual status with few having had any previous treatment; this is likely to account for the increased prevalence observed. In this study 2% of children were wearing glasses at vision screening, similar to that found in an urban population of children aged 30 to 71 months in the US (1.7%),[21] but substantially lower than the 4.4% of 6-year-old children in Australia.[19] Another UK cohort study[23] reported 0.6% prevalence of poor presenting visual acuity at the age of 7 years; however 3% of the children in their sample had undergone previous treatment. The prevalence reported in the US study was 1.2% in White children and 1.8% in Black children.[21] In our study 2.7% of White British, 5.2% of Pakistani children and 2.8% of other ethnicities had VA worse than 0.3 logMAR. In both studies the differences in visual acuity between the ethnic groups was not statistically significant.

It has been shown that children from socio-economically deprived households have an increased prevalence of vision problems,[31,32] which may in part be due to inequality in accessing health services.[33] The Bradford vision screening programme covers 97% of children[14] and therefore does not

exclude children from the lower socioeconomic areas. The high levels of deprivation in the city may help explain the higher prevalence level of poor visual acuity. Educational attainment is multifactorial and influenced by social disadvantage and demographic factors, differences manifest early and are demonstrable through gaps in literacy achievement.[27,28] Factors known to be associated with educational outcome such as socioeconomic status,[28,34] gender,[35] and mothers' education[36] were also shown in this study to impact on literacy (Table 2). There was no difference between the literacy scores of the White British and the Pakistani children however there was a positive association between literacy and visual acuity for children in the "other" ethnic category. A third of children in this category had mothers with high educational attainment and this may help explain the association. The association between the level of visual acuity and literacy remains significant after adjustment for socio-economic and demographic factors (Table 2).

Low degrees of refractive error, in particular, hyperopia are normally reported in young children.[37] A few studies have found that low degrees of uncorrected hyperopia in young children have an impact on literacy.[38,39] Non-cycloplegic autorefraction was used in this study to provide an indication of refractive status. Commonly non-cycloplegic refraction underestimates the level of hyperopia present in young children,[40] auto refraction using the Welch-Allyn has however been shown to have a small hyperopic bias[41] which could have increased the reported mean spherical equivalent of the Bradford population (Table 1). All children who failed their vision screening assessment were referred for a cycloplegic examination to confirm refractive error; an on-going longitudinal study of these children will examine the results. In this study our analysis demonstrates an association between literacy and visual acuity but not refractive error.

A small number of population based studies have examined the impact of visual acuity on educational outcome. A US study evaluating the effect of visual function on academic performance (children aged 6-9 years) found no association. However, the key indicator of academic performance (Metropolitan Readiness Test) was not available for a large proportion of the children and a proxy measure of attainment was used, neither did the study take into account the effects of potential confounding factors.[42] Retrospective analysis of the 1958 British birth cohort reporting outcomes at age 11 years found no association between unilateral amblyopia and educational, health and social outcomes, however, participants with bilateral visual loss were excluded from the study.[43] A large cohort study in

Singapore reported no effect of presenting visual acuity on academic school performance[44] but the Singapore cohort of children at age 9 – 10 years only included a small number of children with poor vision which reduced the power of the study to detect any significant association.

Our paper reports the largest population based study which explores the impact of visual acuity on literacy and has a number of strengths. The cohort is set in a multi-ethnic population and the use of data linkage has allowed us to undertake rigorous analysis taking into account the effect of potential confounding factors. However, there are limitations, 2929 out of 5836 (50%) of BiB children had received a literacy test at the time of data linkage; this reduced the number of children (n= 2025) who had complete data sets and may compromise the representativeness of the sample. However, comparison of the Born in Bradford children (n=2025) with complete data demonstrated a similar percentage of children within each quintile of the Index of Multiple Deprivation and is comparable to the complete BiB cohort of children (n=13773).[10] The prevalence of poor vision in this cohort of children (n=2025) is also similar to all Bradford children (n=11186) (Table S1). As a proxy indicator for English as a second language we used the language in which the baseline questionnaire was completed by the mother during pregnancy. Although all children are taught in school in English this may not be the primary language of choice at home; this information was not available.

The study has the inherent limitations of a cross sectional design, which reduces our ability to confidently infer causality. However, it is unlikely that poor literacy resulted in poor performance in the vision test; the majority of children (98%) performed the recommended age appropriate vision test and the association between vision and literacy remained after excluding children unable to accomplish the letter matching. In addition, if indeed poor literacy causes poor vision we would expect that those children with specific reading difficulties (dyslexia) would demonstrate reduced visual acuity. In a recent study 4 out of 5 children with reading difficulties demonstrated normal visual function.[45]

By linking the clinical data set from the population based vision screening programme with epidemiological data from a large birth cohort study, along with the baseline literacy assessments, this is the first multi-ethnic population based study to have the statistical power to take into account the multiple factors that are known to impact on educational outcomes. Our results demonstrate a

significant association between visual acuity and early literacy. In a population with a high prevalence of reduced vision this has important implications for children's future educational outcomes. The reduction in the literacy score by around 2% for every line of vision reduction is important in a population where there are poor levels of vision on school entry. This study strengthens the argument for a national vision screening programme. The impact of such a programme will depend on the degree to which detection of reduced vision at age 4-5 years results in effective intervention to improve vision and the impact this has on health, educational and social outcomes. Further research is required to determine the extent to which children with poor vision access treatment and the impact of such treatment not only on levels of vision but also on their educational attainment.

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Contributors AB initiated the project, designed data collection, monitored data collection for the whole study, wrote the statistical analysis plan, cleaned and analysed the data, and drafted and revised the paper. She is guarantor. LF wrote the statistical analysis plan, cleaned the data and revised the draft paper. BC and JW initiated the project and revised the draft paper. TS initiated the project, wrote the statistical analysis plan and revised the draft paper.

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Data sharing No additional data available

Competing Interests None declared

Ethics approval National Research Ethics Committee Yorkshire & the Humber- South Yorkshire (Ref 13/YH/0379).

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Legend Figure 1
Figure1. Flow chart of data linked between Bradford Vision screening programme, Starting Schools and Born in Bradford participants. BiB = Born in Bradford.

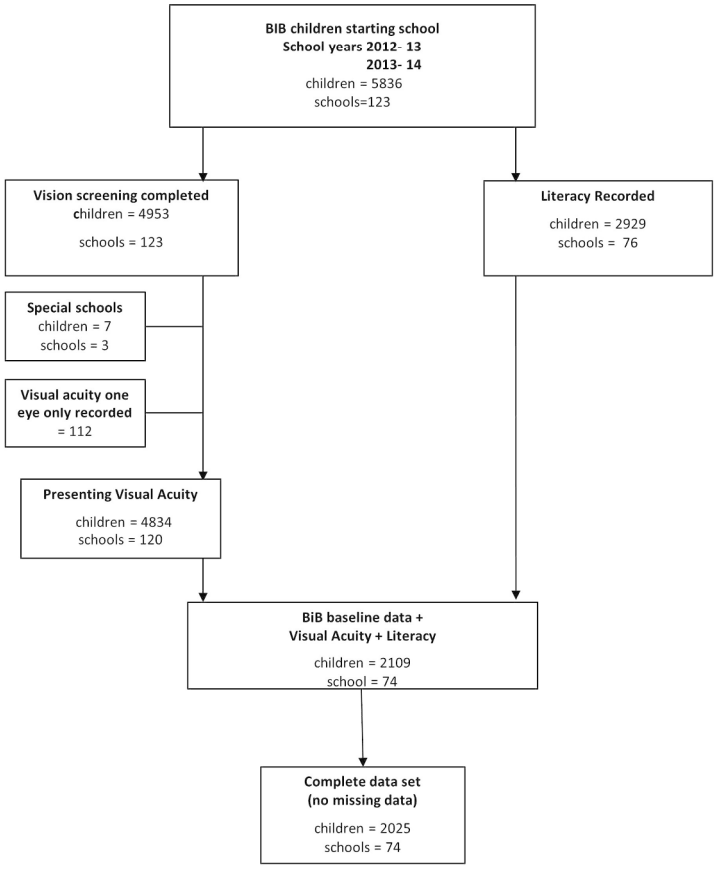

Figure1. Flow chart of data linked between Bradford Vision screening programme, Starting Schools and Born in Bradford participants. BiB = Born in Bradford.

190x274mm (284 x 284 DPI)

Table S1. Comparison of Born in Bradford (BiB) Children with Non-Born in Bradford Children.

Characteristic	**All children** mean (SD) (range)	**Non-BiB children** mean (SD)	**BiB children** mean (SD)	**Mean Difference (95% CI)**
Letter ID score	105.64 (12.78) (68-143) n=6249	104.7 (12.98) n=3320	106.7 (12.46) n=2929	-1.99 (-2.62 to -1.36)
British Picture Vocabulary Score	99.03 (16.43) (39 to 161) n=6160	97.96 (17.55) n=3268	100.23 (14.97) n=2892	-2.28 (-3.09 to -1.46)
Visual Acuity (logMAR)	0.137 (0.09) (0 to 1.0) n= 12083	0.139 (0.09) n=7215	0.134 (0.09) n=4868	0.005 (0.002 to 0.008)
Mean Spherical Error (Dioptres)	1.05 (0.69) (-5.6 to +9.74) n=11483	1.04 (0.71) n=6871	1.06 (0.67) n=4612	0.02 (-0.046 to 0.005)

Table S2. Associations between Literacy (Letter Identification Score) and Visual Acuity, British Picture Vocabulary Scale (BPVS), Socio-economic and demographic (child and maternal) factors n=1979 children n= 74 school

FACTOR	UNADJUSTED mean difference in literacy scores (95% CI)	ADJUSTED BPVS mean difference in literacy scores (95% CI)	ADJUSTED DEMOGRAPHIC mean difference in literacy scores (95% CI) *	ADJUSTED SOCIOECONOMIC mean difference in literacy scores (95% CI) **	FULLY ADJUSTED MODEL mean difference in literacy scores (95% CI) ***
change in literacy score per 1 line (0.1log unit) of Visual Acuity	-2.41 (-2.97 to -1.85) p<0.001	-1.83 (-2.37 to -1.29) p<0.001	-1.76 (-2.29 to -1.23) p<0.001	-1.76 (-2.29 to -1.23) p<0.001	-1.69 (-2.21 to -1.16) p<0.001
change in literacy score per 1 unit change in BPVS		0.26 (0.23 to 0.30) p<0.001	0.26 (0.22 to 0.30) p<0.001	0.25 (0.22 to 0.29) p<0.001	0.24 (0.21 to 0 .28) p<0.001
Ethnicity					
White British			reference		reference
Pakistani			1.08 (-0.56 to 2.72) p=0.196		0.10 (-1.6 to 1.8) p= 0.91
Other			3.78 (1.84 to 5.73) p<0.001		2.86 (0.88 to 4.84) p=0.005
Sex at birth					
Male			reference		reference
Female			2.8 (1.82 to 3.79) p<0.001		2.86 (1.88 to 3.84) p<0.001
Birth weight (g)			0.001 (0.0003 to 0.003) p=0.015		0.001 (0.0002 to 0.002) p=0.021
Gestational age (weeks)			0.046 (-0.32 to 0.41) p=0.806		0.027 (-0.33 to 0.39) p=0.883
Questionnaire Language					
English			1.94 (0.35 to 3.52) p=0.016		1.8 (0.22 to 3.4) p=0.026
Other language			reference		reference
UK born					
Yes			1.33 (-0.15 to 2.81) p=0.077		1.12 (-0.35 to 2.59) p=0.14
No			reference		reference
Receiving Benefits					
Yes				-0.98 (-2.01 to 0.05) p=0.062	-0.96 (-1.97 to 0.05) p=0.063
No				reference	reference
Level of Education					
Low (<5 GCSE equivalent & unknown)				reference	reference
Medium (5 GCSE & A level equivalent)				0.99 (-0.19 to 2.16) p=0.099	0.96 (-0.22 to 2.15) p=0.11
High (higher than A-level)				3.00 (1.46 to 4.50) p<0.001	2.91 (1.4 to 4.41) p<0.001
Smoked in pregnancy					
Yes				-2.38 (-3.87 to -0.88) p=0.002	-1.94 (-3.5 to -0.36) p=0.016
No				reference	reference

*Demographic adjustment includes; Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mother place of birth.
**Socioeconomic adjustment includes; Visual Acuity, BPVS, receipt of benefits, level of mothers' education, mother smoked during pregnancy.
***Fully adjusted analysis includes all factors Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth, receipt of benefits, level of mothers education ,mother smoked during pregnancy.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p2.
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p3. & p4.
Objectives	3	State specific objectives, including any prespecified hypotheses	P3.
Methods			
Study design	4	Present key elements of study design early in the paper	p4. & p5.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p4. p5. & p6.
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	p4. p5. & p6.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p4. p5. & p6.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p4. p5. p6. and Table 1
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	p4. p5. p6. and Figure 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p6. & p7.
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p6. & p7.
		(*b*) Describe any methods used to examine subgroups and interactions	p7.
		(*c*) Explain how missing data were addressed	p6. & p7.
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	p7.

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Figure 1 & p6
		(b) Give reasons for non-participation at each stage	Figure 1 & p6
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1 & Supplementary Table S1
		(b) Indicate number of participants with missing data for each variable of interest	Figure 1
Outcome data	15*	Report numbers of outcome events or summary measures	p8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	p8 & Table 2
		(*b*) Report category boundaries when continuous variables were categorized	p6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	p8 & supplementary Table S2
Discussion			
Key results	18	Summarise key results with reference to study objectives	p10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p11 & p12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p10,p11,p12 & Table 3
Generalisability	21	Discuss the generalisability (external validity) of the study results	p12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p13

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The Impact of Visual Acuity on Developing Literacy at age 4-5 years: a cohort nested cross sectional study

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The Impact of Visual Acuity on Developing Literacy at age 4-5 years: a cohort nested cross sectional study.

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The Impact of Visual Acuity on Developing Literacy at age 4-5 years: a cohort nested cross sectional study.

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ABSTRACT

Objectives To estimate the prevalence of poor vision in children aged 4-5 years and determine the impact of visual acuity on literacy.

Design Cross sectional study linking clinical, epidemiological and education data.

Setting Schools located in the city of Bradford, UK.

Participants Prevalence was determined for 11186 children participating in the Bradford school vision screening programme. Data linkage was undertaken for 5836 Born in Bradford (BiB) birth cohort study children participating both in the Bradford vision screening programme and the BiB Starting Schools Programme. 2025 children had complete data and were included in the multivariable analyses.

Main outcome measures Visual acuity was measured using a logMAR Crowded Test (higher scores = poorer visual acuity). Literacy measured by Woodcock Reading Mastery Tests-Revised (WRMT-R) subtest: Letter Identification (standardised).

Results The mean (SD) presenting visual acuity was 0.14 (0.09) logMAR (range 0.0 to 1.0). 9% of children had a presenting visual acuity worse than 0.2logMAR (failed vision screening), 4% worse than 0.3logMAR (poor visual acuity) and 2% worse than 0.4logMAR (visually impaired). Unadjusted analysis showed that the literacy score was associated with presenting visual acuity, reducing by 2.4 points for every 1 line (0.10logMAR) reduction in vision (95%CI -3.0 to -1.9). The association of presenting visual acuity with the literacy score remained significant after adjustment for demographic and socio-economic factors reducing by 1.7 points (95%CI -2.2 to -1.1) for every 1 line reduction in vision.

Conclusion Prevalence of decreased visual acuity was high compared to other population based studies. Decreased visual acuity at school entry is associated with reduced literacy. This may have important implications for the children's future educational, health and social outcomes.

Strengths and limitations of this study

- Data linkage provides a comprehensive data set which allowed adjustment for confounding factors.
- This is one of the first studies to investigate the impact of reduced vision on educational attainment.
- The study is based in a large multi-ethnic population
- The study is limited by its cross-sectional nature.
- Not all participants have complete data sets for all the variables.

INTRODUCTION

The United Kingdom National Screening Committee (UK NSC) recommends that vision screening should be provided to all children at age 4-5 years;[1] these recommendations form part of the Healthy Child Programme.[2] However the evidence supporting this recommendation is weak. In particular, there are limited data on the prevalence of vision levels in children at age 4-5 years when they first enter school, and the effect of reduced vision on educational attainment in children has not yet been established.[1, 3] Early literacy is a key indicator of future reading performance and educational attainment[4 ,5] which in turn affects long term health and social outcomes.[6 ,7] It is intuitive that poor vision will impact on a child's reading ability and lead to educational underachievement, yet there is little evidence to confirm this. At a time of change and uncertainty in the commissioning of vision screening services it is important to understand both the level of vision in the population and the impact this is likely to have on future health and social outcomes.[8 ,9] Better evidence is therefore required to inform child screening policy both in the UK and internationally.

The aim of this study is to determine the prevalence of poor vision in a multi-ethnic population and explore the impact of reduced vision on developing literacy skills in young children as they commence primary school at age 4-5 years.

One of the challenges to the investigation of a causal relationship between vision and literacy is the potential confounding effect of socioeconomic factors. It is well known that socioeconomic deprivation

is associated with poor levels of literacy; therefore any study seeking to explore the degree to which poor vision affects literacy over and above effects of socioeconomic and other demographic factors requires comprehensive data collection.

The city of Bradford in the UK offers the opportunity to conduct such a study because it is the setting for the Born in Bradford (BiB) birth cohort study[10] which collected detailed epidemiological data during pregnancy, at birth and literacy measures in a sub-group of the children in their first year of school. Bradford also has a comprehensive vision screening programme which provides a detailed profile of children's vision. These data provide the unique opportunity to explore the association between visual acuity and early developing literacy with adjustment for the effects of potential confounding variables.

METHODS

Vision screening and literacy measures were prospectively collected from children in their first year of primary school within the same school term over two consecutive years (2012 - 2013 and 2013 - 2014). Vision screening data from all participants was used to determine the prevalence of poor vision. Baseline epidemiological data collected from mothers and children of the Born in Bradford cohort, literacy measures and data captured from the vision screening programme were linked in order to investigate the impact of vision on literacy. Details of each element are provided below. Ethics approval for the data linkage was granted by National Research Ethics Committee Yorkshire & the Humber- South Yorkshire (Ref 13/YH/0379).

Born in Bradford (BiB)

Born in Bradford (BiB) is a longitudinal multi-ethnic birth cohort study aiming to examine the impact of environmental, psychological and genetic factors on maternal and child health and wellbeing.[10] Bradford is a city with high levels of socio-economic deprivation and ethnic diversity. Approximately half of the births in the city are to mothers of South Asian origin. Women were recruited while waiting for a glucose tolerance test, routinely offered to all pregnant women registered at the Bradford Royal Infirmary at 26-28 weeks gestation. For those consenting, a baseline questionnaire was completed. The full BiB cohort recruited 12,453 women during 13,776 pregnancies between 2007 and 2010 and

the cohort is broadly representative of the city's maternal population.[10] Ethics approval for the data collection was granted by Bradford Research Ethics Committee (Ref 07/H1302/112).

Literacy

As part of a separate Born in Bradford "Starting Schools Programme" exploring literacy, movement and wellbeing, children's literacy levels on school entry were measured in school by experienced research assistants. All 123 Bradford primary schools were invited to participate, 76 separate schools agreed to take part and 2929 BiB children received a literacy assessment between September 2012 and July 2014.

Early literacy skills that predict future reading performance include letter identification.[4] Letter identification measures the child's ability to identify single letters, an essential skill mastered prior to reading and one of the best predictors of reading achievement.[11] Letter identification was measured using the Woodcock Reading Mastery Tests-Revised (WRMT-R) subtest: Letter Identification, a validated reading skill test.[12]

In addition, a measure of acquired or receptive vocabulary was recorded using the British Picture Vocabulary Scale (BPVS).[13] It has been shown to be an important indicator of cognitive ability, providing a representation of the measure of IQ in young children. This measure is included to adjust for potential confounding due to levels of general cognitive ability.

Both measures are standardised taking into account the child's age and time of testing during the academic year, a mean score of 100 would be expected for a given population.[12, 13]

Vision

A vision screening programme for 4-5 year old school children has been established in Bradford. The screening programme is conducted in school by orthoptists. Due to the nature of the programme being conducted after school entry coverage is high at 97%.[14] 11186 children from 123 primary schools across the city participated in the vision screening programme. 5836 BiB children were eligible for the study (started school between September 2012 and July 2014) and 4953 (85%) BiB children had completed the vision screening programme prior to the data linkage (Figure 1). The vision screening assessment includes standard protocols for measurement of distance visual acuity[15]

[16] right and left eyes, with spectacles if worn. The visual acuity test was administered by orthoptists, performed at a distance of three metres and visual acuity was measured to threshold (i.e. best achievable visual acuity with no defined endpoint). Additional tests carried out by the orthoptists were cover test, ocular motility and non-cycloplegic auto refraction (Welch-Allyn Inc. Skaneateles. NY). Visual acuity was measured with an age appropriate LogMAR Crowded Test (Keeler, Windsor)[15] which has four letters per line each letter having a score of 0.025; the total score for each line represents 0.1 log unit. A matching card is used and knowledge of letters is not necessary to perform the test. 4834 children completed the vision screening and had visual acuity recorded for both right and left eyes (Figure 1). 118/4834 (2%) of children were unable to match letters, they were tested using Kay Pictures Crowded LogMAR (Kay pictures, Tring UK).[17,18] Refractive error is commonly associated with reduced visual acuity in young children,[19] hence non-cycloplegic autorefractor readings for the right and left eyes were recorded and a mean spherical equivalent (sphere plus half-negative cylinder) calculated for each eye of individual children.[19,20] 4578 out of 4834 children had a mean spherical equivalent calculated. Data from the vision screening programme used for the analyses includes presenting visual acuity (best visual acuity right or left eye, with glasses if worn) and the mean spherical equivalent from that same eye.

Presenting visual acuity will be referred to as visual acuity for the rest of the paper and in all tables. Visual acuity was categorised to examine prevalence of levels of vision. Four categories were established: better than 0.20 logMAR (a pass on visual screening), 0.225 to 0.30, 0.325 to 0.40, (referred to as “poor vision” in many published studies)[19,21] and worse than 0.4 (a category used to define visual impairment by the World Health Organisation).[22] Visual acuity was treated as a continuous variable in the statistical modelling allowing for letter by letter scoring.

Statistical analysis

Multi-level regression analysis (children nested within schools) was undertaken in BiB children where complete data sets from both the mother and child were available, 84 of 2109 children were excluded due to incomplete data (Figure 1). This was mainly due to incomplete data on the BPVS which was not recorded in 60 (3%) children. To analyse the effect of visual acuity on literacy, unadjusted analysis was undertaken on BiB children with complete data (n=2025). Subsequent adjustment for

demographic and socioeconomic (maternal and child characteristics) including BPVS score to account for cognitive ability was then undertaken. The characteristics included in the statistical analysis were those found to be associated with both educational and visual outcomes in the current literature. Demographic factors were: ethnicity (determined by the mothers' ethnicity), sex at birth, birth weight, gestational age, language of baseline questionnaire completed by mother, mothers' place of birth. Socio-economic factors were: mother in receipt of benefits, level of mothers' education, mother smoked during pregnancy. [23-28] The characteristics are detailed in Table 1.

Table 1. Distribution of Characteristics in Born in Bradford (BiB) Children with Complete Data.

Characteristic	Mean (SD)	
Letter ID score	107.07 (12.5)	range 68 to 143
Visual Acuity (logMAR)	0.13 (0.09)	range 0.0 to 0.8
British Picture Vocabulary Score	100.97 (14.47)	range 39 to 160
Mean Spherical Equivalent* (D)	1.07 (0.64)	range -2 to +9.5
Birth weight (g)	3191 (541)	range 680 to 5180
Gestational age (weeks)	39.14 (1.63)	range 27 to 43
Sex at birth (M:F)	1010:1015	
Ethnicity**	**n (%)**	
White British	671 (33.2)	
Pakistani	1106 (54.6)	
Other	248 (12.2)	
Baseline Questionnaire Language**	**n (%)**	
English	1541 (76)	
Other language	484 (24)	
UK born mother**	**n (%)**	
Yes	1177 (58)	
No	848 (42)	
Receiving Benefits**	**n (%)**	
Yes	880 (43.46)	
No	1145 (56.54)	
Mothers Level of Education**	**n (%)**	
Low (<5 GCSE equivalent & unknown)	567 (28)	
Medium (5 GCSE & A level equivalent)	1050 (52)	
High (higher than A-level)	408 (20)	
Mother Smoked in pregnancy**	**n (%)**	
Yes	282 (14)	
No	1743 (86)	

D = dioptres
*n=1893 all other variables n=2025
**Determined by mothers' response to the baseline questionnaire.

The regression analyses were undertaken in three steps; firstly demographic factors (listed above) were included in the model, a second model was then run adjusting for the socio-economic factors (listed above) and finally a fully adjusted model was run adjusting for all demographic and socioeconomic factors and the BPVS score for general cognitive ability. In all these models 2025 children from 74 schools were included.

Further regression analysis was undertaken to examine the impact of mean spherical equivalent on a subsample with complete data available (n=1893). A sensitivity analysis was also undertaken excluding children unable to carry out letter matching (n=1979). Multi-level analysis was undertaken

in order to account for variability between schools; the variance in attainment attributed to differences between schools was calculated to provide a variance partition coefficient for each model. All analyses were carried out using Stata 13 (StataCorp, College Station, TX).

RESULTS

The overall mean (SD) visual acuity for all children (n=11186) who received vision screening was 0.14 (0.09) logMAR (range 0.0 to 1.0). 8.7% (977/11186) of children had a visual acuity worse than 0.2logMAR, 4% (475/11186) worse than 0.3logMAR and 1.8% (206/11186) of children demonstrated a visual acuity of worse than 0.4logMAR. There was no clinically significant difference between the BiB and non-BiB children (supplementary Table S1).

The univariate and adjusted model analyses for the BiB children are shown in Table 2. Unadjusted analysis of the BiB children (n=2025) showed that the literacy score was associated with the level of visual acuity. The literacy score reduced by 2.42 points for every 1 line (0.10logMAR) reduction in visual acuity (95% CI -2.98 to -1.87) p<0.001. When adjusted to account for cognitive ability (BPVS), demographic factors or socio-economic factors the impact of visual acuity remained significant and continued to remain statistically significant in the multivariable model after all factors are accounted for with the literacy score reducing by 1.65 (95% CI -2.17 to -1.13) p<0.001 for every 1 line (0.10logMAR) reduction in visual acuity . The association between visual acuity and literacy remained after a sensitivity analysis was undertaken to investigate the effect of poor literacy by excluding children unable to carry out the letter matching (supplementary Table S2). Adjustment for mean spherical equivalent made no material difference and by itself was not associated with literacy (p=0.164) it therefore was not included in the model. The variance in attainment attributed to the difference between schools was 9% in the unadjusted model and 12% in the fully adjusted model across 74 schools.

Table 2. Associations between Literacy (Letter Identification Score) and Visual Acuity, British Picture Vocabulary Scale (BPVS), Socio-economic and Demographic (child and maternal) factors n=2025 children n= 74 schools.

FACTOR	UNADJUSTED mean difference in literacy scores (95% CI)	ADJUSTED BPVS mean difference in literacy scores (95% CI)	ADJUSTED DEMOGRAPHIC mean difference in literacy scores (95% CI) *	ADJUSTED SOCIOECONOMIC mean difference in literacy scores (95% CI) **	FULLY ADJUSTED MODEL mean difference in literacy scores (95% CI) ***
change in literacy score per 1 line (0.1log unit) of Visual Acuity	-2.42 (-2.98 to -1.87) p<0.001	-1.79 (-2.32 to -1.26) p<0.001	-1.72 (-2.24 to -1.19) p<0.001	-1.72 (-2.25 to -1.19) p<0.001	-1.65 (-2.17 to -1.13) p<0.001
change in literacy score per 1 unit change in BPVS		0.27 (0.23 to 0.30) p<0.001	0.26 (0.22 to 0.30) p<0.001	0.25 (0.22 to 0.29) p<0.001	0.25 (0.21 to 0 .28) p<0.001
Ethnicity					
White British			reference		reference
Pakistani			0.83 (-0.82 to 2.47) p=0.325		-0.14 (-1.86 to 1.58) p= 0.872
Other			3.79 (1.86 to 5.73) p<0.001		2.85 (0.88 to 4.82) p=0.005
Sex at birth					
Male			reference		reference
Female			3.01 (2.03 to 3.99) p<0.001		3.06 (2.09 to 4.04) p<0.001
Birth weight (g)			0.001 (0.0001 to 0.002) p=0.028		0.001 (0.0001 to 0.002) p=0.036
Gestational age (weeks)			0.006 (-0.35 to 0.37) p=0.975		-0.01 (-0.37 to 0.34) p=0.937
Questionnaire Language					
English			1.78 (0.21 to 3.35) p=0.026		1.61 (3.18 to 0.04) p=0.045
Other language			reference		reference
UK born					
Yes			-1.19 (-2.66 to 0.28) p=0.113		-0.97(-0.49 to 2.43) p=0.192
No			reference		reference
Receiving Benefits					
Yes				-1.05 (-2.06 to 0.03) p=0.043	-1.03 (-2.04 to -0.03) p=0.045
No				reference	reference
Level of Education					
Low (<5 GCSE equivalent & unknown)				reference	reference
Medium (5 GCSE & A level equivalent)				1.14 (-0.024 to 2.3) p=0.055	1.13 (-0.04 to 2.3) p=0.059
High (higher than A-level)				3.30 (1.8 to 4.8) p<0.001	3.20 (1.71 to 4.70) p<0.001
Smoked in pregnancy					
Yes				-2.19 (-3.68 to -0.69) p=0.004	-1.82 (0.25 to 3.39) p=0.023
No				reference	reference

*Demographic adjustment includes; Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth.

**Socioeconomic adjustment includes; Visual Acuity, BPVS, receipt of benefits, level of mothers' education, mother smoked during pregnancy.

***Fully adjusted analysis includes all factors Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth, receipt of benefits, level of mothers education ,mother smoked during pregnancy

DISCUSSION

This study is the first to reliably demonstrate that poor visual acuity in young children is associated with reduced early developing literacy. The average receptive vocabulary and slightly above average literacy scores (Table 1) of the children indicate that general low achievement does not influence our findings. The mean visual acuity (Table 1) of these 4 -5 year old children is similar to previously published normative data,[29] however, our findings indicate a high proportion of children (9%) had reduced visual acuity with 2% classified as visually impaired.[22] This is likely to impact significantly on their early developing literacy. The Bradford cohort of children demonstrates a higher prevalence of poor presenting visual acuity (defined as worse than 0.3 logMAR) compared to that reported elsewhere.[19,21,23,30] (Table 3).

Author	Community	Age (years)	No. of participants	Prevalence (%)
Robaei D, Rose K, Ojaimi E, et al.[19]	Australia	6-7	1738	0.9
Friedman DS, Repka MX, Katz J, et al.[21]	USA	2.5-5.5	1714	1.5
Williams C, Northstone K, Howard M, et al.[23]	Bristol, UK	7	7825	0.6
O'Donoghue L, McClelland JF, Logan NS et al[30]	Northern Ireland, UK	6-7	392	1.5
Bruce A, Fairley L, Chambers B, et al	Bradford, UK	4-5	11186	4.0

Table 3.Comparison of studies reporting prevalence of poor visual acuity (worse than 0.30logMAR)

For the majority of children in Bradford, vision screening at school entry is their first assessment of visual status with few having had any previous treatment; this is likely to account for the increased prevalence observed. In this study 2% of children were wearing glasses at vision screening, similar to that found in an urban population of children aged 30 to 71 months in the US (1.7%),[21] but substantially lower than the 4.4% of 6-year-old children in Australia.[19] Another UK cohort study[23] reported 0.6% prevalence of poor presenting visual acuity at the age of 7 years; however 3% of the children in their sample had undergone previous treatment. The prevalence reported in the US study was 1.2% in White children and 1.8% in Black children.[21] In our study 2.7% of White British, 5.2% of Pakistani children and 2.8% of other ethnicities had VA worse than 0.3 logMAR. In both studies the differences in visual acuity between the ethnic groups was not statistically significant.

It has been shown that children from socio-economically deprived households have an increased prevalence of vision problems,[31,32] which may in part be due to inequality in accessing health services.[33] The Bradford vision screening programme covers 97% of children[14] and therefore does not exclude children from the lower socioeconomic areas. The high levels of deprivation in the city may help explain the higher prevalence level of poor visual acuity. Educational attainment is multifactorial and influenced by social disadvantage and demographic factors, differences manifest early and are demonstrable through gaps in literacy achievement.[27,28] Factors known to be associated with educational outcome such as socioeconomic status,[28,34] gender,[35] and mothers' education[36] were also shown in this study to impact on literacy (Table 2). There was no difference between the literacy scores of the White British and the Pakistani children however there was a positive association between literacy and visual acuity for children in the "other" ethnic category. A third of children in this category had mothers with high educational attainment and this may help explain the association. The association between the level of visual acuity and literacy remains significant after adjustment for socio-economic and demographic factors (Table 2).

Low degrees of refractive error, in particular, hyperopia are normally reported in young children.[37] A few studies have found that low degrees of uncorrected hyperopia in young children have an impact on literacy.[38,39] Non-cycloplegic autorefraction was used in this study to provide an indication of refractive status. Commonly non-cycloplegic refraction underestimates the level of hyperopia present in young children,[40] auto refraction using the Welch-Allyn has however been shown to have a small hyperopic bias[41] which could have increased the reported mean spherical equivalent of the Bradford population (Table 1). All children who failed their vision screening assessment were referred for a cycloplegic examination to confirm refractive error; an on-going longitudinal study of these children will examine the results. In this study our analysis demonstrates an association between literacy and visual acuity but not refractive error.

A small number of population based studies have examined the impact of visual acuity on educational outcome. A US study evaluating the effect of visual function on academic performance (children aged 6-9 years) found no association. However, the key indicator of academic performance (Metropolitan Readiness Test) was not available for a large proportion of the children and a proxy measure of attainment was used, neither did the study take into account the effects of potential confounding

factors.[42] Retrospective analysis of the 1958 British birth cohort reporting outcomes at age 11 years found no association between unilateral amblyopia and educational, health and social outcomes, however, participants with bilateral visual loss were excluded from the study.[43] A large cohort study in Singapore reported no effect of presenting visual acuity on academic school performance[44] but the Singapore cohort of children at age 9 – 10 years only included a small number of children with poor vision which reduced the power of the study to detect any significant association.

Our paper reports the largest population based study which explores the impact of visual acuity on literacy and has a number of strengths. The cohort is set in a multi-ethnic population and the use of data linkage has allowed us to undertake rigorous analysis taking into account the effect of potential confounding factors. However, there are limitations, 2929 out of 5836 (50%) of BiB children had received a literacy test at the time of data linkage; this reduced the number of children (n= 2025) who had complete data sets and may compromise the representativeness of the sample. However, comparison of the Born in Bradford children (n=2025) with complete data demonstrated a similar percentage of children within each quintile of the Index of Multiple Deprivation and is comparable to the complete BiB cohort of children (n=13773).[10] The prevalence of poor vision in this cohort of children (n=2025) is also similar to all Bradford children (n=11186) (Table S1). As a proxy indicator for English as a second language we used the language in which the baseline questionnaire was completed by the mother during pregnancy. Although all children are taught in school in English this may not be the primary language of choice at home; this information was not available.

The study has the inherent limitations of a cross sectional design, which reduces our ability to confidently infer causality. However, it is unlikely that poor literacy resulted in poor performance in the vision test; the majority of children (98%) performed the recommended age appropriate vision test and the association between vision and literacy remained after excluding children unable to accomplish the letter matching. In addition, if indeed poor literacy causes poor vision we would expect that those children with specific reading difficulties (dyslexia) would demonstrate reduced visual acuity. In a recent study 4 out of 5 children with reading difficulties demonstrated normal visual function.[45]

By linking the clinical data set from the population based vision screening programme with epidemiological data from a large birth cohort study, along with the baseline literacy assessments, this is the first multi-ethnic population based study to have the statistical power to take into account the multiple factors that are known to impact on educational outcomes. Our results demonstrate a significant association between visual acuity and early literacy. In a population with a high prevalence of reduced vision this has important implications for children's future educational outcomes. The reduction in the literacy score by around 2% for every line of vision reduction is important in a population where there are poor levels of vision on school entry. This study strengthens the argument for a national vision screening programme. The impact of such a programme will depend on the degree to which detection of reduced vision at age 4-5 years results in effective intervention to improve vision and the impact this has on health, educational and social outcomes. Further research is required to determine the extent to which children with poor vision access treatment and the impact of such treatment not only on levels of vision but also on their educational attainment.

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Contributors AB initiated the project, designed data collection, monitored data collection for the whole study, wrote the statistical analysis plan, cleaned and analysed the data, and drafted and revised the paper. She is guarantor. LF wrote the statistical analysis plan, cleaned the data and revised the draft paper. BC and JW initiated the project and revised the draft paper. TS initiated the project, wrote the statistical analysis plan and revised the draft paper.

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Data sharing No additional data is available

Competing Interests None declared

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Legend Figure 1
Figure1. Flow chart of data linked between Bradford Vision screening programme, Starting Schools and Born in Bradford participants. BiB = Born in Bradford.

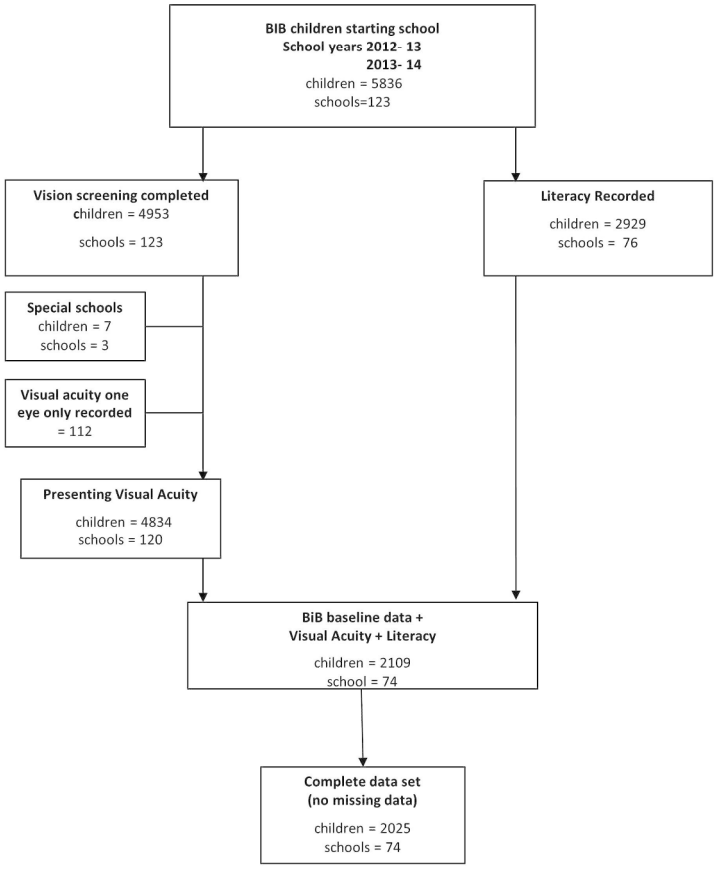

Figure 1. Flow chart of data linked between Bradford Vision screening programme, Starting Schools and Born in Bradford participants. BiB = Born in Bradford.

180x260mm (300 x 300 DPI)

Table S1. Comparison of Born in Bradford (BiB) Children with Non-Born in Bradford Children.

Characteristic	**All children** mean (SD) (range)	**Non-BiB children** mean (SD)	**BiB children** mean (SD)	**Mean Difference (95% CI)**
Letter ID score	105.64 (12.78) (68-143) n=6249	104.7 (12.98) n=3320	106.7 (12.46) n=2929	-1.99 (-2.62 to -1.36)
British Picture Vocabulary Score	99.03 (16.43) (39 to 161) n=6160	97.96 (17.55) n=3268	100.23 (14.97) n=2892	-2.28 (-3.09 to -1.46)
Visual Acuity (logMAR)	0.137 (0.09) (0 to 1.0) n= 12083	0.139 (0.09) n=7215	0.134 (0.09) n=4868	0.005 (0.002 to 0.008)
Mean Spherical Error (Dioptres)	1.05 (0.69) (-5.6 to +9.74) n=11483	1.04 (0.71) n=6871	1.06 (0.67) n=4612	0.02 (-0.046 to 0.005)

Table S2. Associations between Literacy (Letter Identification Score) and Visual Acuity, British Picture Vocabulary Scale (BPVS), Socio-economic and demographic (child and maternal) factors n=1979 children n= 74 school

FACTOR	UNADJUSTED mean difference in literacy scores (95% CI)	ADJUSTED BPVS mean difference in literacy scores (95% CI)	ADJUSTED DEMOGRAPHIC mean difference in literacy scores (95% CI) *	ADJUSTED SOCIOECONOMIC mean difference in literacy scores (95% CI) **	FULLY ADJUSTED MODEL mean difference in literacy scores (95% CI) ***
change in literacy score per 1 line (0.1log unit) of Visual Acuity	-2.41 (-2.97 to -1.85) p<0.001	-1.83 (-2.37 to -1.29) p<0.001	-1.76 (-2.29 to -1.23) p<0.001	-1.76 (-2.29 to -1.23) p<0.001	-1.69 (-2.21 to -1.16) p<0.001
change in literacy score per 1 unit change in BPVS		0.26 (0.23 to 0.30) p<0.001	0.26 (0.22 to 0.30) p<0.001	0.25 (0.22 to 0.29) p<0.001	0.24 (0.21 to 0 .28) p<0.001
Ethnicity					
White British			reference		reference
Pakistani			1.08 (-0.56 to 2.72) p=0.196		0.10 (-1.6 to 1.8) p= 0.91
Other			3.78 (1.84 to 5.73) p<0.001		2.86 (0.88 to 4.84) p=0.005
Sex at birth					
Male			reference		reference
Female			2.8 (1.82 to 3.79) p<0.001		2.86 (1.88 to 3.84) p<0.001
Birth weight (g)			0.001 (0.0003 to 0.003) p=0.015		0.001 (0.0002 to 0.002) p=0.021
Gestational age (weeks)			0.046 (-0.32 to 0.41) p=0.806		0.027 (-0.33 to 0.39) p=0.883
Questionnaire Language					
English			1.94 (0.35 to 3.52) p=0.016		1.8 (0.22 to 3.4) p=0.026
Other language			reference		reference
UK born					
Yes			1.33 (-0.15 to 2.81) p=0.077		1.12 (-0.35 to 2.59) p=0.14
No			reference		reference
Receiving Benefits					
Yes				-0.98 (-2.01 to 0.05) p=0.062	-0.96 (-1.97 to 0.05) p=0.063
No				reference	reference
Level of Education					
Low (<5 GCSE equivalent & unknown)				reference	reference
Medium (5 GCSE & A level equivalent)				0.99 (-0.19 to 2.16) p=0.099	0.96 (-0.22 to 2.15) p=0.11
High (higher than A-level)				3.00 (1.46 to 4.50) p<0.001	2.91 (1.4 to 4.41) p<0.001
Smoked in pregnancy					
Yes				-2.38 (-3.87 to -0.88) p=0.002	-1.94 (-3.5 to -0.36) p=0.016
No				reference	reference

*Demographic adjustment includes; Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mother place of birth.
**Socioeconomic adjustment includes; Visual Acuity, BPVS, receipt of benefits, level of mothers' education, mother smoked during pregnancy.
***Fully adjusted analysis includes all factors Visual Acuity, BPVS, ethnicity, sex at birth, birth weight, gestational age, language of baseline questionnaire, mothers place of birth, receipt of benefits, level of mothers education ,mother smoked during pregnancy.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p2.
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p3. & p4.
Objectives	3	State specific objectives, including any prespecified hypotheses	P3.
Methods			
Study design	4	Present key elements of study design early in the paper	p4. & p5.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p4. p5. & p6.
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	p4. p5. & p6.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p4. p5. & p6.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p4. p5. p6. and Table 1
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	p4. p5. p6. and Figure 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p6. & p7.
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p6. & p7.
		(*b*) Describe any methods used to examine subgroups and interactions	p7.
		(*c*) Explain how missing data were addressed	p6. & p7.
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	p7.

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Figure 1 & p6
		(b) Give reasons for non-participation at each stage	Figure 1 & p6
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1 & Supplementary Table S1
		(b) Indicate number of participants with missing data for each variable of interest	Figure 1
Outcome data	15*	Report numbers of outcome events or summary measures	p8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	p8 & Table 2
		(*b*) Report category boundaries when continuous variables were categorized	p6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	p8 & supplementary Table S2
Discussion			
Key results	18	Summarise key results with reference to study objectives	p10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p11 & p12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p10,p11,p12 & Table 3
Generalisability	21	Discuss the generalisability (external validity) of the study results	p12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p13

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.