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ORIGINAL ARTICLE

Worsening vision at age 4–5 in England post-COVID: Evidence from a large database of vision screening data

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Abstract

Purpose: Myopia prevalence has increased in the UK at age 10-16y, but little is known about younger children. We hypothesise that if the 'myopia epidemic' is affecting young children, then there will be increasing rates of bilateral reduced unaided vision (V) at vision screenings of children 4–5 years of age.

Methods: Retrospective anonymised data from computerised vision screening at age 4–5 years were analysed from serial cross-sectional data. Refractive error is not assessed in UK vision screening, so vision was investigated. Data were only included from schools that screened every year from 2015/16 to 2021/22. The criterion used was unaided monocular logMAR (automated letter-by-letter scoring) vision >0.20 in both the right and left eyes, so as to maximise the chances of detecting bilateral, moderate myopia rather than amblyopia.

Results: Anonymised raw data were obtained for 359,634 screening episodes from 2075 schools. Once schools were excluded where data were not available for every year and data were cleaned, the final database comprised 110,076 episodes. The proportion (percentage and 95% CI) failing the criterion from 2015/16 to 2021/22 were 7.6 (7.2–8.0), 8.5 (8.1–8.9), 7.5 (7.1–7.9), 7.8 (7.4–8.2), 8.7 (8.1–9.2), 8.5 (7.9–9.0) and 9.3 (8.8–9.7), respectively. The slope of the regression line showed a trend for increasing rates of reduced bilateral unaided vision, consistent with increasing frequency of myopia ($p = 0.06$). A decreasing linear trendline was noted for children 'Under Professional Care'.

Conclusions: For children 4–5 years of age, there were signs of reduced vision over the last 7 years in England. Consideration of the most likely causes support the hypothesis of increasing myopia. The increase in screening failures highlights the importance of eye care in this young population.

KEYWORDS
children, myopia, school screening, vision screening

INTRODUCTION

Increasing prevalence of myopia

In Asian pre-school[1] and kindergarten[2] children, myopia has emerged as more common than hypermetropia, affecting 18% of children by the age of 6 years.[3] In the UK, McCullough et al.[4] reported that in children 10–16 years of age, the proportion of myopes had more than doubled over the preceding 50 years and that children were becoming myopic at a younger age. Therefore, it is not surprising that an increase in myopia prevalence in young children has also been demonstrated in many studies of Western populations summarised below. Inevitably, prevalence rates are dependent on the criteria used to classify types of refractive error and this is discussed below.

Mayro et al.[5] examined 2942 children in Philadelphia who failed vision screening and found 13.1% to have uncorrected refractive error, with mild myopia being the most common refractive error even in children 5–6 years of age. In a study of nearly 8000 predominantly Hispanic children 6 months to 6 years of age, myopia was more common than hypermetropia.[6] In contrast, two studies of young Danish children (conducted before the COVID pandemic) either found a low prevalence of myopia or that significant hypermetropia was more common than myopia.[7,8]

In the Netherlands, Iyer et al.[9] reviewed three pre-COVID population-based studies of nearly 110,000 children. Overall, 2.4% of 6-year-olds and 4.0% of 7-year-olds had myopia (≤−0.50 D), with or without astigmatism. This is lower than the prevalence of 4.8% found in children having a mean age of 6.8 years reported (before COVID) in Tibet.[10] This same paper also cited a prevalence of 4.0% in a 7-year-old population from Poland, similar to the Iyer et al. Netherlands findings described above. Also before COVID, data from the UK Aston Eye Study found a prevalence of myopia of 9.4% (for 6–7 years of age),[11] which was higher than that found in Northern Ireland (1.9% at 6–7 years of age).[4]

Costa et al.[12] screened 1080 first-grade (mean age 6 years) children in Brazil and found the prevalence of significant myopia (15%) to be similar to that of hypermetropia (18%), and far more common than amblyopia (5%). In a North American population of 563 pre-kindergarten children (mean age 4.9 years), Guo et al.[13] found myopia (≤−0.50 D) to be more prevalent than hypermetropia (≥+0.50 D).

Before the COVID pandemic, there were indications that the prevalence of myopia in young Asian children, although high, had stabilised.[3,14] Several studies indicated that lockdowns, home schooling on computers,[15,16] (and/or less time outdoors)[17] as a result of the pandemic were associated with an increased prevalence of myopia in children,[16,18–30] especially at young ages.[31–34] Most of these data come from Asian populations, with similar effects also found in Spanish children 5–7 years of age[31] and in Argentina.[25] Klaver et al.[35] described this as 'quarantine myopia' and noted that younger children may be particularly susceptible to myopic triggers from the environment.

Vision screening

Children's vision screening in the UK normally occurs at 4–5 years of age, with the primary goal of detecting amblyopia.[36] In Sweden, there is evidence that well-implemented vision screening can lead to a reduction in the prevalence of amblyopia in adults.[37] In 2013, an external review against programme appraisal criteria asked whether the current UK screening at age 4–5 years met National Screening Committee (NSC) criteria.[38] The review 'found no robust evidence to support significant changes to the content of the current NSC recommended vision screening programme of children aged 4–5 years in the UK', but did not consider whether a broadening of the programme was appropriate to consider myopia and/or older children.

Key Points

- Retrospective data from a large, unselected sample are suggestive of increased rates of bilateral reduced vision in 4- to 5-year-old children in England.
- Vision screening at 4–5 years of age, originally purposed to detect amblyopia, may provide an insight into increasing myopia in this age group.
- The present research highlights the importance of eye care in children 4–5 years of age.

More recently, a study noted that the UK is an outlier in only screening children's vision once, at 4–5 years of age, but found this to be cost-effective.[39] A systematic review from this time argued that the UK screening programme was preferable for detecting amblyopia when compared with autorefraction or photorefraction at a younger age.[40]

A systematic review of clinical practice guidelines to support the World Health Organization's (WHO) package of eye care interventions found four guidelines on child vision screening; three in the USA and one in the UK.[41] These guidelines generally concentrated on amblyopia and all guidelines considered were at least 5 years old.

Often, publications on vision screening still centre on the detection of amblyopia,[42] although several studies have noted a much higher prevalence of refractive errors in preschool[1] and schoolchildren compared with amblyopia.[5,43,44] In children 4–5 years of age, previously undiagnosed visual defects are most likely to be due to refractive errors and parents/carers are usually unaware of these.[45] Bruce et al.[46] investigated children in this age range who failed a vision screening in Bradford, UK. The screening results were cross-referenced with data from the Born-in-Bradford birth cohort study to determine the risk factors for children who failed vision screening. There was a higher risk of failing the vision screening in those with Pakistani origin, increased maternal age at pregnancy, low birth weight and families receiving benefits.

Ideally, screening tests should be evaluated in research where all participants receive both the screening test and a 'gold standard' verification.[47,48] There has been a dearth of research of this type evaluating UK vision screening at 4–5 years of age. A notable exception was a study by McCullough and Saunders[45] who applied the NSC protocol to 294 children between 4 and 5 years of age in Northern Ireland. All participants underwent screening and optometric testing including cycloplegic autorefraction and ocular alignment. Despite difficulties in detecting hypermetropia, overall vision screening had moderately good sensitivity (70.4%) and specificity (82.2%). Of the 7.8%

of children who were found to be normal on the vision screening but exhibited a visual anomaly on optometric testing, all but one had hypermetropia, with the other case having anisometropia and astigmatism. No case of myopia was undetected by screening.

Although typical screening programmes in the UK have changed little over the last decade, in other countries, there have been several studies evaluating modern technologies designed to screen for refractive error.[49–53] The American Association for Pediatric Ophthalmology and Strabismus (AAPOS) has developed guidelines on devices that can detect significant refractive errors and amblyopia risk factors.[54] The relevance of these guidelines to myopia detection is considered further below. Some authors have criticised the UK system of vision screening at ages 4–5 years only, arguing for additional screening episodes at ages 7 and 11,[55] or one other screening intervention at 11 years of age.[56]

Vision screening for myopia

The increasing prevalence of myopia has led to interest in vision screening for refractive errors,[9,10,57–59] particularly myopia.[10,60–62] A literature search was undertaken (November 2022) using PubMed, Embase, Web of Science and Google Scholar[63] for papers in the last 10 years (2012–2022) for vision + screening AND myopia AND child. The review below concentrates on studies of screening methodology in children 4–6 years of age in Europe, although key studies relating to other regions and ages are also considered.

A challenge with comparing studies is that the increasing prevalence of myopia from birth to adulthood[43] means that the age at which a population is tested is critical. Studies with broad age ranges (e.g., 3–12 years)[64] are therefore not considered in this literature review. Another major confounding variable is the criterion used to define myopia, with various values chosen by different authors, for example, ≤−0.50 D,[13,45,46,64–68] <−0.50 D,[3,69] ≤−1.00 D,[70] <−2.00 D[53] or ≤−3.25 D.[71] Additional confounders include decisions about whether to consider the least myopic meridian, most myopic meridian or spherical equivalent refraction, and whether to apply these criteria to the better eye, worse eye or the mean of the two monocular results.

Lin et al.[57] compared four screening strategies for detecting myopia: (1) cycloplegic autorefraction, (2) non-cycloplegic autorefraction, (3) distance uncorrected visual acuity and (4) combined uncorrected visual acuity and non-cycloplegic autorefraction. Not surprisingly, (1) and (4) gave the best sensitivity although distance uncorrected visual acuity gave reasonable sensitivity (58%) and excellent specificity (94%). Indeed, the ease and low cost of visual acuity testing probably explains why most studies that have screened for myopia have relied on this form of testing.

Thomas et al.[58] compared three different visual acuity tests for detecting refractive errors in preschool children (mean age of 5 years) in India. Although good sensitivities (~90%) and specificities (~70%) were reported, the results are difficult to interpret because coarse cut-offs were used for defining significant refractive errors (>+3.25 D for hypermetropia and <−2.00 D for myopia). Their first figure indicates that hypermetropia was far less common than myopia.

When using visual acuity tests to screen for myopia, the pass/fail criterion is important. This was investigated by Tong and colleagues who compared two visual acuity charts, an Early Treatment of Diabetic Retinopathy Study (ETDRS) logMAR chart used by optometrists and a simplified 7-line visual acuity screening chart used by school nurses. The optimum threshold for the simplified screening chart was 6/12 (which the authors noted had been used historically), while for the ETDRS chart was 0.26 logMAR for the detection of myopia and 0.18 logMAR for the detection of any refractive error. The 95% limits of agreement for the two methods were −0.22 to +0.34. The authors concluded that 'the intuitive threshold of 6/12 used in screening seems to be the optimal level'. A later study by O'Donoghue et al.[70] in children 6–7 and 12–13 years of age found that logMAR visual acuity screening can reliably detect myopia, but not hypermetropia or astigmatism. The cut-off used by O'Donoghue et al.[70] for failing was vision >0.20 logMAR in either or both eyes. This is a widely used criterion[45,66,72] for children aged 4–5 years[45,73] (as recommended by Public Health England)[36] as well as those 5–6 years of age.[74]

Wilkinson and Wilson[75] questioned whether screening for myopia in New Zealand meets the Wilson and Jungner criteria; a process previously undertaken in the UK by Thomson and Evans.[76] Wilkinson and Wilson found that paediatric vision screening would meet seven of the 10 criteria, and recommended further research on developing vision screening to identify early myopia and provide treatment to slow its progression.

Luo et al.[59] evaluated a smartphone application (app) that measured distance visual acuity, reporting success in detecting myopia. The authors concluded that the app could potentially be used for myopia screening. A recent study from China found that the largest myopic shift occurred at 3 years of age, which may be related to the beginning of kindergarten.[77] The authors advocated vision screening of children for refractive error beginning at 3 years of age.

The AAPOS uniform guidelines for instrument-based paediatric vision screening still centre on detecting amblyopic risk factors, but also include 'significant refractive errors'.[54] The emphasis on amblyopia in these guidelines is likely to influence the cut-off for 'visually significant' myopia of <−3.00 D under 4 years of age and <−2.00 D after 4 years.[54] In contrast, 2011 guidelines for spectacle prescribing in infants and children advocate the correction of myopia <−1.00 D from 4 years of age to the early school

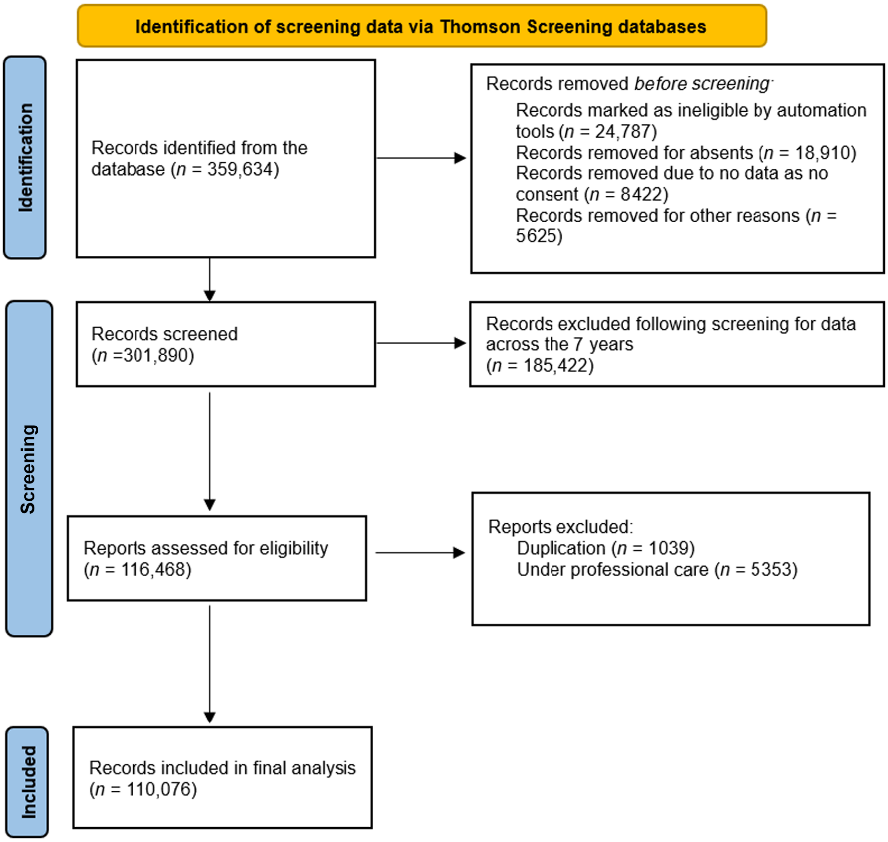

FIGURE 1 A flow diagram summarising the identification of vision screening data used for the final analysis.

years, and full correction of school age myopia.[78] A more contemporary view is that the earliest possible detection of myopia is important so that myopia control (management) can be considered. This is especially important for younger children because even in Europeans with relatively low myopia (−0.50 D to −1.50 D) at 10 years of age there is a 33% risk of going on to develop high myopia by 25 years of age.[79]

Vision screening in the UK occurs at ages 4–5, and although originally purposed to detect amblyopia, vision screening data may also provide an insight into increasing myopia at this age. The purpose of the present study was to use vision screening data from a large cohort of schools over several years, including post-COVID, to investigate whether the data are compatible with increasing myopia at this young age.[31,32]

In 1999, Thomson and Evans[76] described a new computerised approach to vision screening in schools. Subsequently, this software was developed based on the UK Public Health England (PHE) criteria.[36] The resulting SchoolScreener® software is designed to support orthoptist-led vision screening programmes in schools, irrespective of who is delivering the service.[80] The software manages and automates all requirements for school-based screening (vision and hearing) and healthcare programmes. This includes managing screening through a laptop computer without requiring any clinical knowledge, and also automating associated administrative processes. Since 2013, this instrument has been used in over 3000 schools. The present study is based on de-identified data from the SchoolScreener.

METHODS

The UK Health Research Authority (HRA) confirmed that the study is an audit not requiring HRA review. The study was approved by the Institute of Optometry Ethics Committee and conformed to the tenets of the Declaration of Helsinki.

The researchers were given access by Thomson Screening to anonymised records of over 300,000 computerised screening test results from 2015/16 to 2021/22. The screening data included a unique child identifier number, a school code (different for each school using the screener), each child's date of birth (amended for anonymisation to the first day of the month in which they were born), the date of vison screening, vision in the right and left eyes (logMAR, automated letter-by-letter scoring) and the screening classification. The screening classification was one of the following: Pass, Fail right eye, Fail left eye, Fail both eyes, Forced referral (due to a concern raised during the screening, e.g., the screener suspected a developmental problem) or Under Professional Care (UPC, under the care of a primary or secondary eye care practitioner). Children classified as 'UPC' could be under the care of an eye care professional for various bilateral or unilateral conditions, including hypermetropia, myopia, astigmatism, amblyopia, strabismus or other binocular vision conditions. A combination of the child's date of birth and date on which the screening took place was used to calculate each child's age at the time of screening.

A two-stage data clean was performed to obtain the final data set used in the analysis (Figure 1). During the first data clean, the following were deleted: data linked to anomalous school codes; missing data from children who were absent on the day of screening, entries from children who were unable to complete the tests and entries for children whose parents did not consent to the vison screening. To maximise the possibility of detecting any trends in the frequency of reduced visual acuity pre- and post-COVID, the data set was limited to those schools for which there were data across seven academic years from 2015/16 to 2021/22. This led to the second data clean. After this second data clean, the schools included in the analysis were widely distributed across urban and rural areas of England. These data were analysed to determine: (a) any trend in the frequency of bilateral reduced vision before COVID and (b) the effect of COVID on the occurrence of bilateral reduced vision.

Refractive error is not assessed during UK vision screening; therefore, this manuscript concentrates on bilateral reduced unaided vision (V). It seems likely that an increase in the rates of bilateral reduced vision over time will be due to uncorrected myopia, and the validity of this assumption is considered further in the discussion. The criterion used to define bilateral reduced vision was unaided monocular logMAR vision worse than 0.20 in both the right and left eyes. In selecting this criterion, we considered limitations of using unaided vision as indicative of myopia. The use of the >0.20 cut-off in each eye reduces the risk of including amblyopes, but excludes unilateral myopia and bilateral low myopia. The decision not to set a maximum interocular difference criterion has the advantage of not only including anisomyopes but also leads to the inclusion of some amblyopes and others with reduced vision in each eye from hypermetropia/astigmatism. Trends in the data were tested for statistical significance using two approaches. First by combining the standard chi-squared test with the chi-squared test for trend, also known as the Cochran–Armitage test,[81–83] which tests ordered data for the significance of any linear trend in a proportion over time. Second using regression analysis to test if the slope of the straight line fitted to the proportions was statistically significantly different from zero. For both approaches, a trend with $p < 0.05$ was regarded as statistically significant.

RESULTS

Anonymised raw data were obtained for 359,634 screening episodes from 2075 schools. When schools were excluded because data were not available for every year from 2015/16 to 2021/22 and the remaining data were cleaned, the final database comprised 110,076 anonymised screening episodes using the SchoolScreener in 515 different schools between 2015/16 and 2021/22. Table 1 provides an overview of the final sample, giving for each year, the total number of pupils who had their vision tested (10,990–19,184), together with the percentages of those who were 'Pass' on screening (79.9%–83.7%), Fail both eyes (7.5%–9.3%) and Fail one eye (8.8%–10.8%) over the course of seven academic years. Across the middle of the table, we report the total number of children who had their vision tested plus the number of children classified as being UPC for each year (11,489–20,113). The percentage of children classified as UPC ranged from 4.1% to 5.0%, and these children did not have their vision tested during the school screening process. The proportions of males and females in each year were fairly consistent, with a slightly higher proportion of males (50.1%–51.3%) than females (48.7%–49.9%) in the first six academic years. The reverse was true in the final year, 2021/22, with a slightly higher proportion of females (50.2%) compared with males (49.8%). The median age of the full sample was 5.2 years (IQR: 4.9, 5.5).

The trendline for the percentage of 4- to 5-year-old children classified as 'Fail both eyes' during the screening process in each year from 2015/16 to 2018/19 is essentially a flat line (Cochran–Armitage chi-squared test for trend $p = 0.47$), with no evidence of an increase in bilateral reduced vision (defined as $V > 0.20$ logMAR in each eye) over these 4 years (Figure 2a). The two highest, and equal third highest, percentages of 'Fail both eyes' (Table 1) were in the three most recent, COVID-affected years (2019/20–2021/22). For data over the full seven academic years from 2015/16 to 2021/22 (Figure 2b), the trend is for an increasing proportion of 'Fail both eyes', although the slope of the straight line just fails to be significantly different from zero ($p = 0.056$). The chi-squared test for trend gives a p-value of <0.0001. However, to confirm that any linear trend is statistically significant, it is necessary to consider the results of the standard chi-squared test performed on the same data. When these standard test results, which also have a p-value of <0.0001, are considered alongside the trend results, it is not possible to confirm a significant linear trend in the proportion of 'Fail both eyes' between 2015/16 and 2021/22.

For 4- to 5-year-old children who were UPC (Figure 3), the linear trend was in a downward direction, opposite to that for 'Fail both eyes' (Figure 2b). The slope of this straight line was not significantly different from zero ($p = 0.11$), and it was not possible to confirm a statistically significant linear trend in the proportions from the chi-squared tests.

Figure 4a shows the percentage of children who were UPC plus those who were 'Fail both eyes' in each year from 2015/16 to 2021/22 with the linear trend line. While the trend shows a modest increase in the proportion of children who were UPC plus 'Fail both eyes' over time, the trend line was not statistically significant from analyses based on regression ($p = 0.19$) or on the chi-squared tests. Figure 4b shows the percentage of children who

TABLE 1 Overview and characteristics of the final data analysis sample (Vision [V], Under Professional Care [UPC], Inter-quartile Range [IQR]).

V Test outcome	Year 2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22
No. of pupils V tested	16,338	19,184	18,488	17,644	11,203	10,990	16,229
Pass (%) [CI]	13,543 (82.9%) [82.3, 83.5]	15,610 (81.4%) [80.8, 81.9]	15,476 (83.7%) [81.9, 83.0]	14,671 (83.2%) [82.4, 83.5]	9158 (81.7%) [81.0, 82.5]	9052 (82.4%) [81.6, 83.1]	12,964 (79.9%) [79.3, 80.5]
Fail both eyes (%) [CI]	1246 (7.6%) [7.2, 8.0]	1628 (8.5%) [8.1, 8.9]	1387 (7.5%) [7.1, 7.9]	1372 (7.8%) [7.4, 8.2]	970 (8.7%) [8.1, 9.2]	929 (8.5%) [7.9, 9.0]	1504 (9.3%) [8.8, 9.7]
Fail one eye (%) [CI]	1559 (9.5%) [9.1, 10.0]	1946 (10.1%) [9.7, 10.6]	1625 (8.8%) [7.9, 9.0]	1601 (9.1%) [8.7, 9.5]	1083 (9.6%) [9.1, 10.2]	1009 (9.2%) [8.7, 9.8]	1761 (10.8%) [10.4, 11.4]
No. of pupils V tested + UPC	17,192	20,113	19,398	18,553	11,685	11,489	16,999
UPC (%) [CI]	854 (5.0%) [4.7, 5.3]	929 (4.6%) [4.3, 4.9]	910 (4.7%) [4.4, 5.0]	909 (4.9%) [4.6, 5.2]	482 (4.1%) [3.8, 4.5]	499 (4.3%) [4.0, 4.7]	770 (4.5%) [4.2, 4.9]
Fail both eyes + UPC (%) [CI]	2100 (12.2%) [11.7, 12.7]	2557 (12.7%) [12.3, 13.2]	2297 (11.8%) [11.4, 12.3]	2281 (12.3%) [11.8, 12.8]	1452 (12.4%) [11.8, 13.0]	1428 (12.4%) [11.8, 13.1]	2274 (13.4%) [12.9, 13.9]
All fails + UPC (%) [CI]	3659 (21.3%) [20.7, 21.9]	4503 (22.4%) [21.8, 23.0]	3922 (20.2%) [19.7, 20.8]	3882 (20.9%) [20.3, 21.5]	2535 (21.7%) [21.0, 22.5]	2437 (21.2%) [20.5, 22.0]	4035 (23.7%) [23.1, 24.4]
Males (%)	8267 (50.6%)	9845 (51.3%)	9435 (51.0%)	8843 (50.1%)	5722 (51.1%)	5566 (50.6%)	8080 (49.8%)
Females (%)	8071 (49.4%)	9339 (48.7%)	9053 (49.0%)	8801 (49.9%)	5481 (48.9%)	5424 (49.4%)	8149 (50.2%)
Median age (IQR1, IQR3 years)	5.1 (4.9, 5.4)	5.1 (4.9, 5.4)	5.1 (4.9, 5.4)	5.1 (4.9, 5.4)	5.1 (4.9, 5.4)	5.3 (5.0, 5.5)	5.2 (4.9, 5.5)

were UPC plus those who were 'Fail both eyes' and 'Fail one eye' in each year from 2015/16 to 2021/22. The upward linear trend was not statistically significant from analyses based on regression (p = 0.34) or on the chi-squared tests.

DISCUSSION

To the best of our knowledge, the present study is the first that has used retrospective data from a large, unselected sample to investigate vision at 4–5 years of age in England post-COVID 19. Our main finding is that among our sample, there are possible signs from the school screening data of increasing rates of bilateral reduced vision post-COVID in this age group in England, which contrasts with no signs of a similar increase pre-COVID. During the COVID pandemic, lifestyle and behaviours of children, adolescents and adults changed, with increased use of digital screens and a reduction in outdoor activity across the board. Traditional schooling came to a halt and home learning became the new norm.[84] Francisco et al.[84] demonstrated that digital screen use significantly increased and daily physical activity significantly decreased when comparing before and during the COVID-19 pandemic in children and adolescents in Italy, Portugal and Spain. Zhao et al.'s[85] study in China showed that most children in their sample spent more than 3 h daily using digital screens and less than 2 h per day in outdoor activities. The authors are unaware of UK data comparing the use of digital screens and outdoor activity pre- and post-COVID, but it could be expected to follow the Western European pattern described by Francisco et al.[84]

Vision screening in children has been found to be beneficial because it allows early detection and treatment of ocular anomalies[56] and visual problems that may be missed in asymptomatic children.[76] Undiagnosed ocular anomalies can result in amblyopia and poor binocular vision and could impact some children's educational progress and behaviour.[86] Uncorrected hypermetropia and myopia are linked to underachievement in educational assessments and poor academic performance, respectively.[87] Children who fail vision screening in the UK are referred to a community optometrist, hospital optometrist, orthoptist or ophthalmologist within the hospital eye service (HES), depending on the nature of the suspected vision problem. It is noteworthy that factors such as ethnicity, parental income, parents' level of education and attitude towards diagnosis and treatment may influence attendance at appointments.[88]

Any testing of young children that requires a degree of child co-operation will always involve a trade-off between the desirability of early detection and the higher

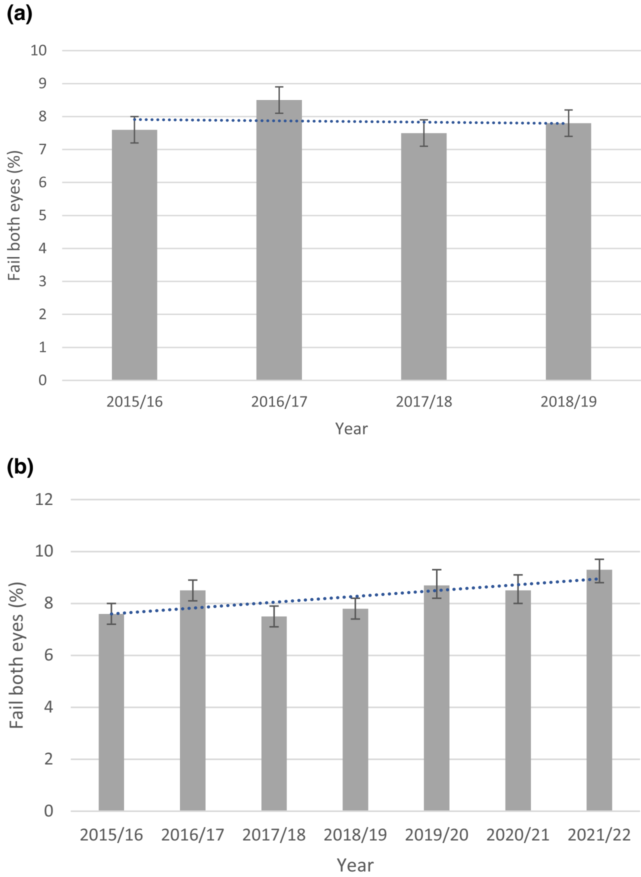

FIGURE 2 (a) Percentage of children in each year from 2015/16 to 2018/19 who were classified as 'Fail both eyes' during the screening test, with the linear trend line. The error bars, for this and all figures below, indicate 95% confidence limits. (b) Percentage of children in each year from 2015/16 to 2021/22 who were classified as 'Fail both eyes' during the screening test, with the linear trend line.

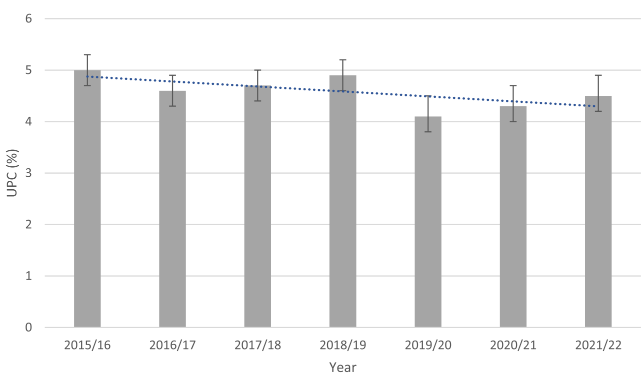

FIGURE 3 Percentage of children Under Professional Care (UPC) in each year from 2015/16 to 2021/22 with the linear trend line.

rates of testability and accuracy with increasing age. Guo et al.[69] cautioned that visual acuity is still developing even at 6 years of age. This is likely to explain, at least in part, why McCullough and Saunders[45] (and others[71]) found in a 4- to 5-year-old population that children who failed a screening were significantly younger (median 5.1 years) than those who passed (median 5.3 years).[45] It is also likely to explain in part why 51.9% of 4- to 5-year-olds who failed the screening had no significant visual issues (false positives).[45] Donaldson et al.[89] reported similar figures, with 43% of children who failed the initial screening being 'visually' normal and discharged at the first visit. More recently, Bruce et al.[46] reported a false positive rate of 7% for their study population of children based in Bradford, UK; comparatively low in contrast with the previous two studies reported here. Objective methods for determining refractive error facilitate earlier screening and in China, such screening has been advocated from 3 years of age.[77]

Overall, 90,474 (82.2%) children in our study achieved presenting vision when viewing with both eyes of 0.20 logMAR or better and 19,620 (17.8%) were referred for follow-up because they were either 'Fail one eye' or 'Fail both eyes' (i.e., $V > 0.20$ logMAR in one or both eyes, respectively). Our findings are comparable with those reported by Bruce et al.[46] who found that 85.1% children achieved $V \leq 0.20$ logMAR and 14.9% were referred for further follow-up because they failed to meet the UK NSC visual acuity pass criteria. Having reviewed the literature on vision screening in children, there is a dearth of comparable data investigating trends in children who 'Pass' and those who 'Fail' vision screening at 4–5 years of age.

A key question is whether the finding of increasing bilateral vision fails since the onset of COVID is indicative of increased myopia. The primary objective of this study was to assess the trend over seven academic years, comparing each year using the same criterion. The incidence of amblyopia and clinically significant hypermetropia are unlikely to have changed over the seven study years. Similarly, although false positives will inevitably account for a proportion of fails in vision screening, it seems unlikely that this would increase significantly as a result of COVID. Some children may have had reduced familiarity with letters due to COVID lockdowns, but testers had the option of switching from letter to picture optotypes when required. Furthermore, children unable to complete the test for any reason were classified as 'unable to complete the test' and were excluded from our data set during the first data clean. Hence, it seems likely that the trend for increasing proportion of 'Fail both eyes' indicates an increasing frequency of 'presumed myopia'.

The downward trend noted in UPCs over time (Figure 3) is opposite to the upward trend for 'Fail both eyes' (Figure 2b). The three lowest percentages of UPC were in the most recent, COVID-affected years (Figure 3). The percentage of UPCs are likely to have decreased in 2019/20 and 2020/21 during periods when optometrists and/or orthoptists were seeing fewer patients because of COVID, and parents were presumably and understandably less enthusiastic about taking their children for an appointment with an eye care professional. This is another possible explanation for the increased proportion of 'Fail both eyes' during the COVID years. Children with reduced vision may have not been identified by eye care professionals because

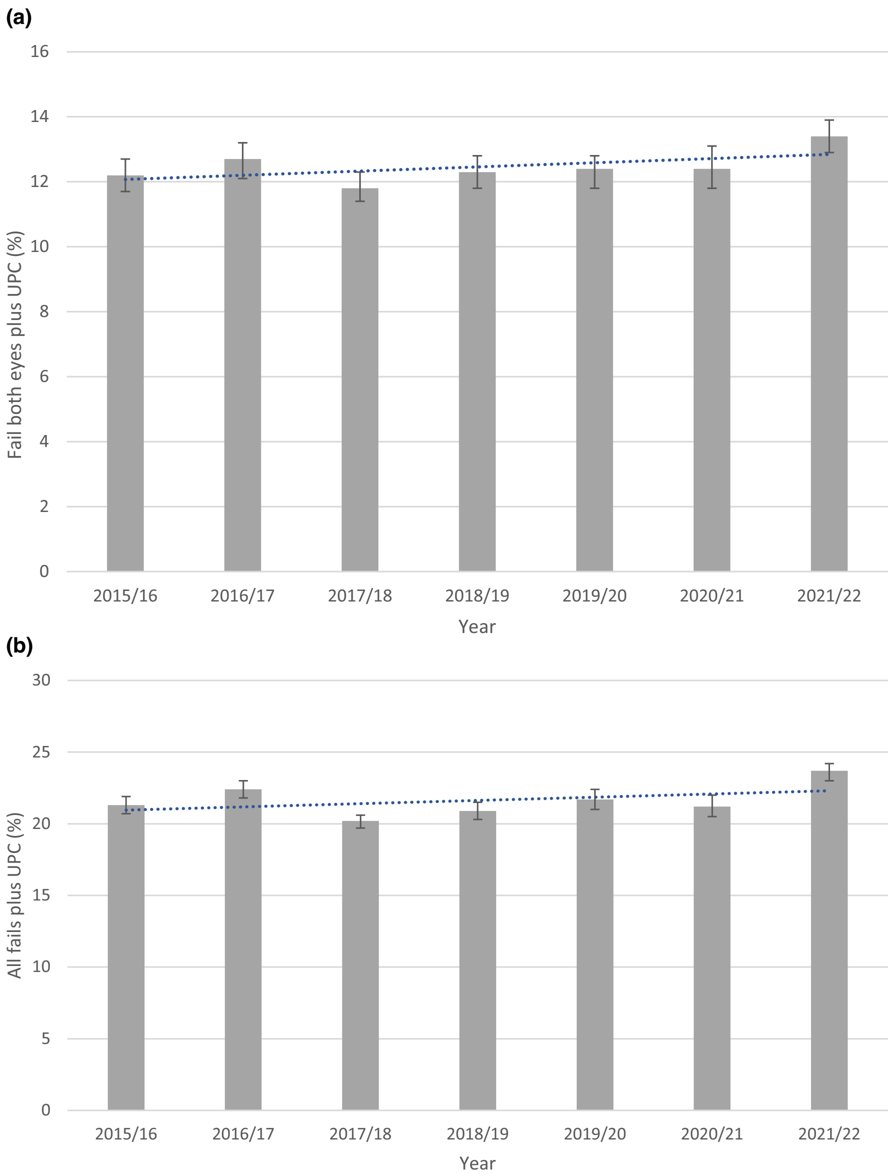

FIGURE 4 (a) Percentage of children Under Professional Care (UPC) plus those who were Fail both eyes in each year from 2015/16 to 2021/22 with the linear trend line. (b) Percentage of children UPC plus all fails in each year from 2015/16 to 2021/22 with the linear trend line.

the children were not presenting. The slight increase in the proportion of UPCs in 2021/22 is not consistent with this explanation, and may reflect an increased willingness to seek professional eye care as the COVID pandemic appeared to become of less concern. Indeed, the increased proportion of UPCs in 2021/22 could be explained by parents 'catching up' with professional eye care as the pandemic receded. However, the concurrent increase in the proportion of 'Fail both eyes' in 2021/22, despite more cases receiving professional care (and therefore being excluded from screening), would again seem most likely to be consistent with an increasing occurrence of myopia. The 8.5% of the sample who were 'Fail both eyes' in 2020/21 was higher than in three of the four pre-COVID years analysed, and equal to the highest percentage recorded in the pre-COVID data. This contributes to the increasing trend of 'Fail both eyes' over the 7-year period analysed. Analysis of these school screening data in future years will allow the permanence and statistical significance of any increase in the proportion of 'Fail both eyes' to be evaluated.

The mean percentage of 'All fails + UPC', an estimate of the proportion of children invited to screening who were either referred for professional care or were already receiving it (see Table 1), was 21.6% (range 20.2%–23.7%). McCullough and Saunders[45] reported that 27.8% of children in their study failed on screening, including 24/284 (8.5%) who had previously been diagnosed with significant refractive errors and habitually wore spectacles, though they completed all the tests in the study without their spectacles. The percentage reported by McCullough and Saunders is higher than the equivalent percentage of UPCs (4.1%–5.0%) in the present study. This could indicate that parents who consented for the McCullough and Saunders study were more likely to have had concerns about their children's vision. In contrast, Bruce et al.[46] recorded presenting visual acuity as that of the better eye with spectacles if owned. 354/16,541 (2.1%) children were wearing glasses at the time of the vision screening, and of these 136/354 did not pass the screening. McCullough and Saunders[45] reported a participation rate of 36% for their study, which is impressive given the battery of tests involved which included cycloplegic autorefraction (see below).

The present authors estimate the participation rate for school vision screening in the study described here to be at least 85%. Approximately 5% of children were absent on the day of the screening and an unknown proportion of these children would have been re-screened on another occasion during that school year. Another notable difference between the present study and that of McCullough and Saunders is the use of a different testing strategy to the SchoolScreener used here. The median ages for both studies were almost identical. The present research has emphasised the importance of eye care in this very young age group, raises interesting questions and has highlighted the need for additional research in this area, including a prospective study assessing the test–retest repeatability, sensitivity and specificity of the SchoolScreener in the 4- to 5-year-old age group.

Strengths and limitations

Strengths of the present work include the large sample size, which resulted in robust estimates of all the proportions quoted in Table 1. Another strength was the use of a population-based (non-clinic) sample. Although participants were not selected as those willing to attend a clinic, and this improves the representativeness of the study, the absence of clinical testing is also the greatest limitation. Specifically, the absence of refractive error assessment means that the present study can only comment with certainty on the increasing number of vision screening fails in young children and therefore the greater need for eye care since the onset of the COVID pandemic. As discussed above, it seems most likely that the increased number of fails in both eyes over recent years is attributable to myopia, but this must remain an inference rather than a finding.

There is inevitably a trade-off in studies between participation rate and the quality and quantity of clinical data. For example, McCullough and Saunders[45] obtained vision screening and rigorous clinical data (including cycloplegic autorefraction), with a participation rate of 36%. The present study achieved an estimated participation rate >85%, but this comes at the cost of not recording refractive error data. Ultimately, it seems likely that both types of studies are necessary to obtain a complete picture. To the best of the authors' knowledge, the test–retest repeatability and intergrader variability of the SchoolScreener have not been assessed, although the repeatability of similar visual acuity tests in children has been explored and the 95% limits of agreement are typically 0.10–0.20 logMAR.[90,91] The SchoolScreener has been compared with the outcomes of a full eye examination, and found to have a sensitivity and specificity of 93.8% and 96.1%, respectively.[75] A further potential limitation is that PHE stipulate that vision screenings should be 'by an orthoptist-led service',[36] and not all of the SchoolScreener schools using the screener were orthoptist led. Also, the researchers were unable to stratify the data by ethnicity to assess trends as ethnicity data are not currently collected by the SchoolScreener software.

A strength of the present work is that schools were only included when screening data were available for all 7 years, to ensure that the study was comparing 'like with like'. An inevitable limitation of this approach is that a large body of data was excluded to achieve this goal. However, it seems unlikely that this exclusion criterion introduced bias.

CONCLUSIONS

In conclusion, even at the young age of 4–5 years, there are possible signs of increasing rates of reduced bilateral vision in England over the last 7 years based on a large data set from an unselected population. It seems most likely that this is attributable to an increasing occurrence of myopia. The lowest percentages for children UPC were noted in the three most recent COVID years, although this reduction does not explain the main finding of increased proportions of children who were 'Fail both eyes' on screening post-COVID.

AUTHOR CONTRIBUTIONS

Rakhee Shah: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (supporting); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **David F. Edgar:** Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (supporting); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Bruce J. W. Evans:** Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (lead); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

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