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ORIGINAL ARTICLE

# Hyperopia in schoolchildren: Investigating the impact on vision and determining appropriate methods for screening

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## Abstract

**Introduction:** Hyperopia is associated with reduced vision and educational outcomes in schoolchildren. This study explored the impact of clinically significant hyperopia (≥+2.00 D) on visual function in schoolchildren and compared the ability of different screening tests (alone and in combination) to detect this level of hyperopia.

**Methods:** Vision testing including monocular logMAR visual acuity (VA) measured to threshold (distance [DVA], near [NVA] and DVA through a plus lens [+2.50 D]), stereoacuity and cycloplegic autorefraction (tropicamide 1%) were undertaken on 263 schoolchildren (mean age: 11.76 years ± 3.38) in Queensland, Australia. Vision measures were compared between children with clinically significant hyperopia in at least one meridian (≥+2.00 D) and emmetropia/low hyperopia (>0.00 and <+2.00 D). Receiver operating curve (ROC) analysis was performed to identify optimal pass/fail criteria for each test and the diagnostic accuracy of individual and combinations of tests.

**Results:** Thirty-two children had clinically significant hyperopia and 225 had emmetropia/low hyperopia. DVA and NVA were worse ($p < 0.01$), while the difference in DVA through a plus lens was less in children with clinically significant hyperopia ($p < 0.01$). ROC analysis for individual tests resulted in areas under the curve (AUCs) ranging from 0.65 to 0.85. Combining screening tests revealed that failing one or more of the following tests was most effective for detecting hyperopia: DVA, NVA and difference in DVA through a plus lens, resulting in a sensitivity and specificity of 72% and 81%, respectively.

**Conclusion:** Significant differences in visual function existed between schoolchildren with clinically significant hyperopia and emmetropia/low hyperopia. Combining measures of DVA and NVA and the difference in DVA through a plus lens demonstrated good discriminative ability for detecting clinically significant hyperopia in this population.

**KEYWORDS**
hyperopia, plus lens test, schoolchildren, vision screening

## INTRODUCTION

During infancy and early childhood, the increased risk of amblyopia and strabismus associated with high levels of hyperopia is well documented.[1,2] This has resulted in the development of paediatric screening guidelines to detect hyperopia as a risk factor for amblyopia and strabismus, through visual acuity (VA) testing and the use of automated vision screeners.[3–5] Different levels of hyperopia are targeted by screenings, dependent on the age of the population. In infants and young children aged 12–48 months, hyperopia of >+4.50 D is classified as an amblyogenic risk factor; this reduces to >+3.00 D in children older than 48 months.[3,4,6,7]

While the benefits of screening for hyperopia at levels considered to be an amblyogenic risk factor are well established, there is less evidence supporting the need for detection and treatment of clinically significant hyperopia in school-aged children older than 7 years, which is typically considered to be beyond the critical period for recovery of VA and stereoacuity in amblyopia.[8] However, clinical trials have shown that amblyopia can be successfully treated in children beyond the critical period,[9,10] providing further justification for the detection and treatment of clinically significant hyperopia in older children. The impact of uncorrected hyperopia on school-aged children can be characterised in terms of both its effect on various vision function measures, typically VA, and how it affects a child's ability to perform daily activities, including reading and other school-based near tasks.[11]

Measures of visual function including distance and near VA (DVA and NVA) and stereoacuity have been shown to be reduced in children with hyperopia compared to non-hyperopic children. Two landmark studies, the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) study which included school-aged children between 6 and 14 years, and the Vision in Preschoolers–Hyperopia in Preschoolers (VIP–HIP) study which included 4–5 year old children, reported decreased distance VA with increasing levels of hyperopia.[12,13] The VIP–HIP study also reported that reductions in both NVA and stereoacuity were more common in children with hyperopia than in emmetropic children.[13] The significance of these differences in visual function between children with hyperopia and emmetropia may explain why reductions in reading and other academic-related performance measures are observed in some hyperopes, and could also improve the effectiveness of vision screening programmes in detecting hyperopia through an appropriate selection of vision tests and appropriate pass/fail criteria.

Many investigations have demonstrated a positive association between uncorrected hyperopia and reduced academic performance, which has been summarised in recent reviews.[14,15] While there is no consensus around the minimum level of uncorrected hyperopia that negatively impacts reading, studies have shown that hyperopia of +1.50 to +2.00 D is associated with poorer academic outcomes and less time spent reading in school-aged children.[16–19] Recent work also demonstrated that correction of even lower levels of hyperopia (≥+1.00 D) improved aspects of near vision in some children (e.g., reductions in accommodative lag and increased reading speed) during sustained near tasks.[20] While more research is required to better understand the impact of hyperopic spectacle correction on vision in children,[15,21] it is clear that many aspects of vision can be impacted by uncorrected hyperopia ≥+2.00 D.

Importantly, ≥+2.00 D hyperopia is also the most prevalent refractive error in some populations. In the Northern Ireland Childhood Errors of Refraction study, 26% of 6 to 7-year-old children had this level of hyperopia, with similar levels (21%) reported in 5 to 7-year-old children in the Chilean cohort of the Refractive Error Study in Children.[22,23] Furthermore, children with this level of uncorrected hyperopia often remain undetected and untreated, with a recent Australian study reporting that one third of school-aged children with clinically significant hyperopia had not had an eye examination, and of those who had, less than a third had been prescribed spectacles.[24] The high prevalence of clinically significant hyperopia in many paediatric populations, together with the fact that it often remains undetected, can have a significant impact on reading and other measures of academic performance. Given that performance can be improved with spectacles,[20] this highlights the need for better methods to detect clinically significant hyperopia in school-aged children.

Screening, however, can be challenging. First, children with hyperopia may be asymptomatic, and second, the most common vision screening test, DVA, may not be

**Key points**

- Children with clinically significant hyperopia (≥+2.00 D) had poorer distance and near visual acuity and better vision through a +2.50 D lens compared to children with emmetropia/low hyperopia (≥0.00 and <+2.00 D).
- Using a common pass/fail criterion for distance visual acuity (>0.20 logMAR), sensitivity and specificity for detecting clinically significant hyperopia were 25% and 98%, respectively. Sensitivity increased to 41% (specificity 94%) when a pass/fail criterion of >0.10 logMAR was applied.
- Distance visual acuity, near visual acuity, and the difference between distance visual acuity and vision through a plus lens were the best combination of screening tests for detecting clinically significant hyperopia, resulting in a sensitivity and a specificity of 72% and 81%, respectively.

sensitive enough to detect clinically significant hyperopia due to the active role of accommodation in children. For example, DVA screening was reported to be ineffective for detecting hyperopia of ≥+2.00 D in schoolchildren aged 6–14 years when using common pass/fail criteria of both 0.20 and 0.30 logMAR.[12] It is often assumed that children have sufficient accommodation to overcome lower levels of hyperopia without correction, resulting in less disruption to VA.[12,20] Indeed, traditional vision screening methods that use the same pass/fail criteria (e.g., the 6/9 line [0.20 logMAR] as a dichotomous pass/fail criterion) for the detection of all refractive errors (myopia, hyperopia and astigmatism), may not be sensitive enough to detect clinically significant hyperopia alone if the cut-off selected is not appropriate.

Alternative strategies to detect clinically significant hyperopia include the use of automated vision screeners, NVA, near stereoacuity tests and the plus lens test. A review of state-based vision screenings in the USA showed that some states (10%) included a screening test that is specifically targeted for hyperopia detection, that is the plus lens test.[25] The plus lens test is predicated on the assumption that children with hyperopia will relax their accommodation and see clearly through the plus lens, whereas children without hyperopia will experience blurred vision and consequently have reduced VA.[26] The plus lens test was first described in the Massachusetts Vision test (1952), and despite a lack of clear protocols and guidelines on the administration of the test, is frequently included in screening protocols.[26,27] In the USA, the following plus lens powers are used in state-based screenings: +2.00, +2.25 and +2.50 D.[28] However, the lack of uniformity regarding the magnitude of the plus power creates challenges in identifying appropriate VA cut-offs.

Given the demonstrated impact of uncorrected hyperopia ≥+2.00 D on visual function (DVA, NVA and stereoacuity), reading performance and other academic outcomes in school-aged children, this magnitude of hyperopia was also referred to as clinically significant in the current study.[12,13,16–19] The aim of the study was therefore to determine which visual function measures were the most effective for detecting clinically significant hyperopia (≥+2.00 D) in school-aged children. Common pass/fail criteria were compared, with the aim of determining optimum referral criteria to maximise the effectiveness of screening for this level of hyperopia.

## METHODS

School students attending a regional primary and secondary school in a town in South-East Queensland, Australia, were invited to participate in the study. The town is located approximately 250 km from the closest major city, and the region is in the lowest 15th percentile of relative socio-economic disadvantage in Australia. No optometry services are available in the town. The closest permanent optometry practice is in a neighbouring town (approximately 50 km away). All children attending the primary and secondary school were invited to participate in the study. Across the two schools, 280 subjects consented to participate and enrolled in the study, which represented a 48% participation rate based on available school enrolment data. Seventeen children did not complete all vision tests, resulting in 263 children with complete data sets. The mean age of the children was 11.76 ± 3.38 years (range: 4.91–18.18 years); 130/263 children were male (49%) and 41% of children reported having had a previous eye examination with an optometrist or had participated in a vision screening.

The study was conducted in accordance with the tenets of the Declaration of Helsinki and was approved by the Queensland University of Technology Human Research Ethics Committee and the Queensland Government Department of Education. Prior written informed consent was obtained from a parent or guardian of each child before their participation in the study. Children were also asked for verbal assent to confirm their willingness to participate in the research.

Children enrolled in the study underwent a comprehensive eye examination performed by experienced paediatric optometrists in a quiet classroom at their school. A detailed description of the methods of this study has been published previously.[24] Vision tests undertaken as part of the comprehensive eye examination included measures of DVA, NVA and stereoacuity. Unaided DVA was measured monocularly using a logMAR letter chart calibrated for 4 m (Good-Lite, good-lite.com). A logMAR Lea symbols chart at 3 m was used for those children who were preliterate ($n = 16$) (Good-Lite, good-lite.com). VA was measured to threshold and each child was encouraged to guess if they reported that they could not read the letters or symbols. Letter-by-letter scoring and a termination rule of stopping after four or more mistakes on a line was used for both the letter and symbol tests.[29] DVA was then immediately remeasured through a plus lens (+2.50 D) monocularly using the same letter or Lea chart. Unaided NVA was measured monocularly at 40 cm with a Lea symbols near logMAR chart using the same procedure for measurement and scoring. Stereoacuity was assessed with children's habitual correction using the Randot stereoacuity test at 40 cm (Stereo Optical Co. Inc., www.stereooptical.com). The level of stereopsis was recorded as the last group of circles correctly identified. Finally, refractive error was determined with cycloplegic autorefraction (Shin-Nippon NVision-K 5001, grandseiko.com), 30 min following instillation of Tropicamide 1% eye drops. This cycloplegic agent was selected as it has a shorter time to peak cycloplegia and a shorter duration of action compared with Cyclopentolate and there is no significant difference in measures of latent hyperopia between Cyclopentolate and Tropicamide.[30] Cycloplegia was confirmed when there was no pupil light response.

Cycloplegia could not be performed on eight children because of contraindications or lack of parental or child consent.

Of the 280 children enrolled in the study, vision testing (including cycloplegic refraction) was completed on 263 schoolchildren. The remaining 17 children completed some components of the study but declined to complete all individual tests: eight children did not consent to cycloplegia, one child declined all VA tests, three did not complete NVA testing, four did not complete the DVA through plus test and one did not complete the stereoacuity test. The 17 children with incomplete data were excluded from the analysis.

Children were classified with clinically significant hyperopia if they had a cycloplegic spherical refractive error of +2.00 D or more in at least one meridian in one or both eyes.[31] A spherical refractive error of plano through to +1.99 D (most hyperopic meridian) was defined as emmetropia/low hyperopia.

## Statistical analysis

Statistical analysis was performed using SPSS version 27.0 (ibm.com). Differences in vision measures (DVA, DVA through plus lens, difference in DVA and DVA through plus lens, NVA and stereoacuity) between children with clinically significant hyperopia and those with emmetropia/low hyperopia were analysed using independent samples *t*-tests. For variables where both right and left eye data were measured (e.g., VA), data from the most hyperopic eye were used. In cases where refractive error was equal between eyes, right eye data was used. $p < 0.05$ was considered statistically significant except for when multiple comparisons were made, where Bonferroni-adjusted *p*-value was used ($p < 0.01$).

The diagnostic accuracy of screening tests for detecting clinically significant hyperopia was determined through calculation of sensitivity, specificity and positive and negative predictive values using the following commonly used published pass/fail criteria.

- Visual acuity:
  - Worse than 0.20 logMAR (distance)[12,32,33]
  - Worse than 0.30 logMAR (near)[13,34]
  - Equal to or better than 0.20 logMAR (distance through +2.50)[35]
  - Equal to or better than 0.20 logMAR difference (two lines) between +2.50 and DVA[36]
- Stereoacuity worse than 60″[13,37]

Sensitivity was the percentage of children with hyperopia (true positive) who failed the screening test and specificity was the percentage of children without hyperopia who passed the screening test (true negative). The positive predictive value was the probability of a child with hyperopia failing the screening test and the negative predictive value was the probability of a child without hyperopia passing the screening test. Receiver operating characteristic curve (ROC) analysis was undertaken to evaluate these criteria by considering the area under the curve (AUC). The AUC can be a value between 0.5 and 1.0, where 1.0 represents perfect accuracy of a test to detect a condition and 0.5 represents poor accuracy.[38] An AUC >0.9 is considered excellent, between 0.8 and 0.9 very good, between 0.7 and 0.8 good, between 0.6 and 0.7 average, and <0.6 poor.[39]

Sensitivity, specificity, and positive and negative predictive values were calculated, and ROC analyses were undertaken on the outcomes of single screening tests as well as combinations of tests. Different combinations of individual tests were determined by selecting the highest performing individual test (based on test sensitivity, when specificity was approaching or >90%), and then increasing the number of tests one at a time in order of individual test performance. A specificity of 90% was selected to allow direct comparisons with other studies.[40]

New pass/fail criteria were also calculated for each individual screening test based on the ROC coordinates that elicited the highest sensitivity when the specificity was approaching or greater than 90%.

# RESULTS

## Comparison of vision measures between children with clinically significant hyperopia and emmetropia/low hyperopia

Thirty-two of the 263 children (12%) were classified as having clinically significant hyperopia ≥+2.00 D (in at least one eye) and 225 children (86%) were classified as having a spherical refractive error of >0.00 and <+2.00 D (emmetropia/low hyperopia). Interestingly, the prevalence of clinically significant hyperopia remained stable across primary (11%, 14/130) and secondary school children (14%, 18/133). Six children (2%) had a myopic refractive error (spherical equivalent ≥−0.25 D) and 41/263 (16%) had astigmatism ≥1.00 D; of these, 8/41 also had hyperopia ≥+2.00 D in at least one meridian, 31/41 were between plano and +2.00 D and 2/41 had myopia ≥0.25 D. Children with myopia were excluded from further analysis, given our focus on screening for hyperopia. Demographic and vision characteristics of emmetropes/low hyperopes ($n = 225$) and clinically significant hyperopes ($n = 32$) are presented in Table 1. The two groups were not significantly different in terms of mean age and gender balance (both $p > 0.10$). Table 1 demonstrates that DVA and NVA were reduced in children with clinically significant hyperopia. Children with clinically significant hyperopia had better DVA through a +2.50 lens and the difference between DVA and DVA through +2.50 (i.e., the

**TABLE 1** Participant characteristics and vision measures of children with clinically significant hyperopia and emmetropia/low hyperopia (mean ± SD); data are for most hyperopic eye.

| | Clinically significant hyperopia ($n = 32$) | Emmetropia/low hyperopia ($n = 225$) | $p$-Value* |
|---|---|---|---|
| Participant characteristics | | | |
| Age (years) | 12.5 ± 3.6 | 11.6 ± 3.4 | 0.16 |
| Gender | 50% female | 51% female | 0.94 |
| Spherical refractive error (D) | +3.28 ± 1.82 | +1.05 ± 0.44 | **<0.001** |
| Cylindrical refractive error (D) | −0.80 ± 0.65 | −0.55 ± 0.32 | 0.04 |
| Vision measures | | | |
| DVA (logMAR) | 0.15 ± 0.27 | −0.04 ± 0.11 | **<0.001** |
| NVA (logMAR) | 0.15 ± 0.31 | −0.03 ± 0.09 | **0.003** |
| DVA through +2.50 (logMAR) | 0.68 ± 0.23 | 0.88 ± 0.13 | **<0.001** |
| Difference between DVA and DVA through +2.50 (logMAR) | 0.53 ± 0.34 | 0.91 ± 0.17 | **<0.001** |
| Stereoacuity (″) | 91 ± 139 | 30 ± 54 | 0.02 |

*Statistically significant Bonferroni-adjusted $p$-values ($p < 0.01$) are in bold.

**TABLE 2** Diagnostic accuracy of single and combinations of different vision tests using existing common pass/fail criteria.

| | Clinical test | Sensitivity | Specificity | PPV | NPV |
|---|---|---|---|---|---|
| Individual tests | DVA (worse than 0.20 logMAR) | 25% (8/32) | 98% (221/225) | 0.67 (8/12) | 0.90 (221/245) |
| | NVA (worse than 0.30 logMAR) | 19% (6/32) | 98% (221/225) | 0.60 (6/10) | 0.89 (221/247) |
| | DVA through +2.50 (better or equal to 0.20 logMAR) | 3% (1/32) | 100% (225/225) | 1.00 (1/1) | 0.88 (225/256) |
| | Difference between DVA and DVA through +2.50 (better or equal to 0.20 logMAR) | 22% (7/32) | 99% (224/225) | 0.88 (7/8) | 0.90 (224/249) |
| | Stereoacuity (worse than 60″) | 25% (8/32) | 95% (214/225) | 0.42 (8/19) | 0.90 (214/238) |
| Combinations of tests[a] | DVA and/or[b] Stereoacuity | 38% (12/32) | 94% (212/225) | 0.48 (12/25) | 0.91 (212/232) |
| | DVA and/or Stereoacuity and/or Difference between DVA and DVA (+2.50) | 41% (13/32) | 94% (212/225) | 0.50 (13/26) | 0.92 (212/231) |
| | DVA and/or Stereoacuity and/or Difference between DVA and DVA (+2.50) and/or NVA | 41% (13/32) | 92% (208/225) | 0.43 (13/30) | 0.92 (208/227) |

Abbreviations: DVA, distance visual acuity; NPV, negative predictive value; NVA, near visual acuity; PPV, positive predictive value.

[a]In order of the highest performing individual tests, based on the highest sensitivity when specificity is approaching or >90%.

[b]Fail criterion was met if at least one of the screening tests was failed.

reduction in VA through plus) was significantly less in the hyperopic group. Children with clinically significant hyperopia also had poorer stereoacuity; however, this difference only approached significance when the analyses were adjusted for multiple comparisons (mean difference = 61″; $p = 0.02$).

## Diagnostic accuracy of screening tests

The sensitivity, specificity, positive and negative predictive values of DVA, NVA, DVA through +2.50, difference in DVA and DVA through +2.50 and stereoacuity, as well as various combinations of these tests using common pass/fail criteria to detect hyperopia (≥+2.00 D), were determined (see Table 2). Individual screening tests are presented first, followed by different combinations of individual tests beginning with the highest performing test (based on test sensitivity, when specificity is approaching or >90%), and increasing the number of tests one at a time in order of individual test performance.

Table 2 demonstrates that using common pass/fail criteria, the individual screening tests that had the highest sensitivity (when specificity was approaching or >90%)

were DVA, with a sensitivity and a specificity of 25% and 98%, respectively, and stereoacuity which had a sensitivity of 25% and a specificity of 95%. The best combination of vision tests was DVA, stereoacuity and the difference in DVA and DVA through +2.50 which elicited a sensitivity and specificity of 41% and 94%, respectively, when at least one of three individual tests was failed.

Receiver operating curve analyses determined the optimal pass/fail criteria (and corresponding sensitivity and specificity) for each of the individual vision tests. The difference between DVA and DVA with +2.50 was the highest performing individual test, with an AUC of 0.85 (0.77–0.94); stereoacuity was the lowest performing test (Figure 1). The optimal criteria that elicited the greatest sensitivity (for a level of specificity approaching or greater than 90%) for each test were DVA and NVA worse than 0.10 logMAR, DVA through +2.50 better or equal to 0.70 logMAR, difference between DVA and DVA through +2.50 better or equal to 0.70 logMAR and stereoacuity worse than 40″ of arc.

Sensitivity and specificity for individual and combinations of tests were then calculated using these optimal pass/fail criteria determined through ROC analysis (Table 3). The difference between DVA and DVA through +2.50 resulted in the highest sensitivity at 66% (specificity = 86%), in detecting clinically significant hyperopia of 2.00 D or more. Specificity reduced and sensitivity increased as individual tests were combined.

## DISCUSSION

The current study explored differences in vision measures in primary and high school children who were classified with either clinically significant hyperopia ≥+2.00 D ($n = 32$) or emmetropia/low hyperopia of ≥0.00 and <+2.00 D ($n = 225$). Compared to the emmetropia/low hyperopia group, children with clinically significant hyperopia had reduced DVA and NVA, better DVA through +2.50 and less difference between DVA and DVA through +2.50. Using the optimum pass/fail criteria derived from the ROC analysis, the difference between DVA and DVA through +2.50 was the highest performing screening test for detecting clinically significant hyperopia. DVA, NVA and difference between DVA and DVA through +2.50 was the best combination of screening tests. The proposed screening cut-off thresholds for detecting clinically significant hyperopia are worse than 0.10 logMAR for DVA and NVA and a difference of 0.70 logMAR or less between DVA and DVA through a +2.50 lens; importantly, this is when VA is measured to threshold.

Both DVA and NVA were reduced in children with clinically significant hyperopia in the current study (DVA and NVA were worse than 0.10 logMAR in 41% of children with ≥+2.00 D, compared with 6% of children with <+2.00 D of hyperopia). This is in general accord with the findings from the CLEERE and VIP–HIP studies. In the CLEERE study that included children aged 6–14 years, more children with hyperopia (≥+2.00 D) failed the VA screening criterion (worse than logMAR 0.20 or 20/30) than children with emmetropia/low hyperopia, (31% vs. 9%).[21] In the VIP–HIP study, both DVA and NVA were reduced in hyperopic children (ages 4–5 years); only 41% of children with moderate hyperopia (+3.00 to +6.00 D) had binocular NVA of 0.10 logMAR, compared with 52% of children with low hyperopia (+1.00 to <+3.00 D) and 64% of children with emmetropia.[13] The VIP–HIP study also compared mean DVA and NVA across emmetropes (<+1.00 D), low (+1.00 to <+3.00 D) and moderate hyperopes (+3.00 to +6.00 D). The mean differences in DVA and NVA between emmetropes and low hyperopes were only 0.01 and 0.02 logMAR, respectively (compared with 0.19 and 0.18 logMAR in the current study). Different approaches to the definitions of hyperopia, as well as in the clinical testing, and the ages of the children involved in these studies may explain the differences in findings. Unlike the current study, neither the CLEERE nor VIP–HIP studies

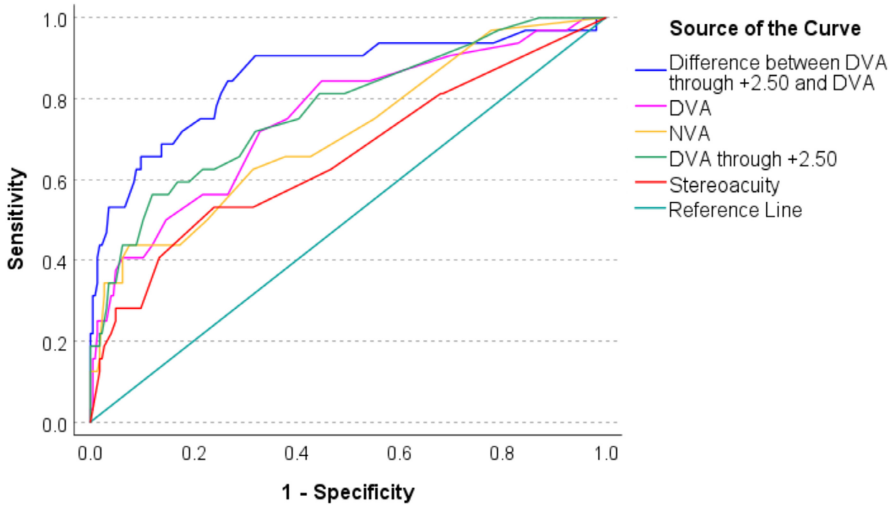


**FIGURE 1** Receiver operating characteristic curves of individual screening tests. DVA, distance visual acuity; NVA, near visual acuity.

**TABLE 3** Diagnostic accuracy of single and combinations of different vision tests using new pass/fail criteria.

| | Clinical test | Sensitivity | Specificity | PPV | NPV | AUC |
|---|---|---|---|---|---|---|
| Individual tests | DVA (worse than 0.10 logMAR) | 41% (13/32) | 94% (211/225) | 0.48 (13/27) | 0.92 (211/230) | 0.75 |
| | NVA (worse than 0.10 logMAR) | 41% (13/32) | 94% (211/225) | 0.48 (13/27) | 0.92 (211/230) | 0.71 |
| | DVA through +2.50 (better or equal to 0.70 logMAR) | 56% (18/32) | 88% (198/225) | 0.40 (18/45) | 0.93 (198/212) | 0.77 |
| | Difference between DVA and DVA through +2.50 (better or equal to 0.70 logMAR) | 66% (21/32) | 86% (194/225) | 0.40 (21/52) | 0.95 (194/205) | 0.85 |
| | Stereoacuity (worse than 40″) | 28% (9/32) | 90% (203/225) | 0.29 (9/31) | 0.90 (203/226) | 0.65 |
| Combinations of tests[a] | Difference between DVA and DVA through +2.50 and/or DVA | 69% (22/32) | 83% (187/225) | 0.37 (22/60) | 0.95 (187/197) | N/A |
| | Difference between DVA and DVA through +2.50 and/or DVA and/or NVA | 72% (23/32) | 81% (182/225) | 0.35 (23/66) | 0.95 (182/191) | |
| | Difference between DVA and DVA through +2.50 and/or DVA and/or NVA and/or Stereoacuity | 75% (24/32) | 77% (173/225) | 0.32 (24/76) | 0.96 (173/181) | |

Abbreviations: AUC, area under the curve; DVA, distance visual acuity; NPV, negative predictive value; NVA, near visual acuity; PPV, positive predictive value.

[a]In order of the highest performing individual tests, based on the highest sensitivity.

measured VA to threshold. A logMAR chart (ranging from 0.80 to 0.00 logMAR) was used in the CLEERE study, with 0.00 logMAR being the best VA achievable; furthermore, children in Grade 1 were stopped after they read the 0.10 logMAR line.[12] The EVA (electronic VA) testing system (Amblyopia Treatment Study protocol) was used to measure VA in the VIP–HIP study; this instrument has a range of 1.60 to −0.10 logMAR and reports VA on a line-by-line basis.[41] Differences in VA between emmetropic and hyperopic groups may have been greater, as was the case in the current study, had vision been measured to threshold in these other studies.

An important finding in the current investigation was that children with clinically significant hyperopia had less reduction in VA when looking through the +2.50 lens compared to children with emmetropia/low hyperopia. Most studies reporting on the plus lens test have only evaluated VA through the plus lens, with only two studies considering the difference in VA through the plus lens and with unaided vision.[26,36] Thomson and Evans[36] recommended that hyperopia be classified when VA was reduced by less than two lines through a +2.50 D lens; however, the accuracy of this criteria was not reported. Interestingly, in the current study a seven-line difference in DVA and DVA through +2.50 D elicited the highest sensitivity, 66% (specificity: 86%; AUC = 0.85), whereas DVA through +2.50 D did not perform as well (sensitivity = 56%, specificity = 88%; AUC = 0.77). This small adjustment in interpreting plus lens test outcomes, as well as clearer protocols for measuring VA in screenings, particularly measuring VA to threshold, would benefit from further research with larger numbers of children with clinically significant hyperopia, as it may be a key for improving hyperopia detection. In addition, while adaptation to the plus lens before remeasuring DVA could further improve hyperopia detection, given that adaptation to a plus lens (20 min) has been shown to relax accommodation in children,[42] the increased time involved would limit its usefulness in a screening context.

The screening test most effective for detecting clinically significant hyperopia in the current study was the difference between DVA and DVA through +2.50 (sensitivity = 66%, specificity = 86%). When multiple screening tests were considered, the most effective combination was the difference between DVA and DVA through +2.50, and DVA and NVA (sensitivity = 72%, specificity = 81%). In the VIP Study, the instruments or tests that had the highest sensitivity for detecting amblyopia, reduced VA, strabismus or significant refractive error in young children were noncycloplegic retinoscopy (81%), Retinomax autorefractor, Nikon.com (78%), SureSight Vision Screener, welchallyn.com (75%) and the Lea Symbols DVA test (70%), when the specificity was 90%.[40] However, the VIP Study did not target hyperopia specifically, but instead investigated conditions that frequently impact VA, and the grouping of refractive error types potentially explains the higher sensitivity of the DVA tests, as VA is a sensitive test for detecting all refractive errors except hyperopia.[12] The VIP Study also did not test to

threshold. Rather, testing was stopped if the smallest line on the chart was seen (0.20 logMAR). In the current study, when a fail criterion of 0.10 logMAR was applied instead of 0.20 logMAR, sensitivity improved from 25% to 41% for detecting clinically significant hyperopia.

This common VA cut-off (0.20 logMAR) was evaluated recently in an Australian study on 4 to 5-year-old children.[33] A sensitivity and a specificity of 80.3% and 95.3%, respectively, was achieved when either the VA test (>0.20 logMAR) or the Spot Vision Screener was failed. A key difference in that study was the vision conditions targeted, specifically, amblyopic risk factors and significant refractive error. The high sensitivity in this study again likely reflects the inclusion of all refractive error types in the screening and the higher cut-off for hyperopia (>3.50 D). However, in school-aged children, lower cut-offs may be more appropriate as the functional impact of hyperopia on academic and reading performance becomes more of a priority. A key strength of the current study is the focus on detecting hyperopia specifically in school-aged children rather than refractive error overall. Hyperopia is the refractive error that is typically the most challenging to detect through vision screenings. The relatively high sensitivity reported in the current investigation is therefore significant, given the target condition. Furthermore, the current analysis only included findings from one eye, while in a screening context, findings from both eyes would be considered, and a fail classified when either eye did not meet the pass criteria or when there were differences in vision between the two eyes which would potentially increase test sensitivity.

A challenge with developing standardised vision screening protocols in school-aged children is the normal spread of expected VA and refractive error in childhood. The VA (worse than 0.10 logMAR) and hyperopia (≥+2.00 D) cut-offs proposed in the current study may be less relevant in a younger age group (4–6 years old), where the expected VA and hyperopic refractive errors are higher than in older schoolchildren. A limitation of the current study was the small sample size of children with clinically significant hyperopia; thus, additional analyses by age were not possible. Further work is indicated to explore age appropriate cut-offs for different screening tests, as well as age appropriate cut-offs for clinically significant hyperopia, given this refractive error decreases with increasing age.

Importantly, the sensitivity of a combination of tests was found to be greater than any individual tests; however, the inclusion of multiple tests in a screening battery increases the time required to complete a screening, which can significantly impact screening programmes that have minimal resources. The balance between the amount of time allocated for each screening and the number of screening tests to include for optimal accuracy can be challenging and may vary depending on resources. Importantly, DVA, DVA through plus and NVA are low-cost solutions that require limited expertise, and with appropriate test sequencing, the testing time could be further reduced (e.g., only DVA through plus and NVA is measured in children who pass DVA).

In summary, the current study proposes that the combination of the difference between DVA and DVA through +2.50, DVA and NVA (using new cut-off levels of 0.10 logMAR for VA) is effective at detecting hyperopia of ≥+2.00 D, achieving a sensitivity and a specificity of 72% and 81%, respectively. This is an important finding for hyperopia screenings and raises the question of whether the existing cut-off of 0.20 logMAR is sensitive enough for detecting hyperopia ≥+2.00 D.

Importantly, this study demonstrated that the improved detection of hyperopia in schoolchildren is achievable using existing vision tests, with minor adjustments to the testing protocol and referral criteria. The high levels of clinically significant hyperopia and its impact on visual function observed in schoolchildren, as demonstrated in the current study, coupled with the fact that these levels are also evident in secondary school children, suggest the potential need for an additional vision screening in schoolchildren conducted later in the school years than the typical screening at school entry for amblyopia. This additional vision screening should target hyperopia by measuring vision to threshold (both unaided and through a plus lens) at a later time point during schooling. This would assist in detecting those children who have failed to emmetropise and would benefit from a full eye examination and refractive correction as appropriate. Further work is required specifically with the plus lens test on larger samples of children with hyperopia, to determine the optimal ages and cut-off thresholds for additional screening.

## AUTHOR CONTRIBUTIONS

**Shelley Hopkins, Scott A. Read, Rebecca A. Cox** and **Joanne M. Wood** contributed to conceptualisation; formal analysis; investigation; project administration; writing—original draft; and writing—review and editing. **Bright A. Oduro** and **Niall Strang** contributed to formal analysis; writing—original draft; and writing—review and editing.

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## CONFLICT OF INTEREST STATEMENT

None.

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