



Vision and academic performance in primary school children

Joanne M Wood¹ , Alex A Black¹, Shelley Hopkins¹ and Sonia L J White²

¹School of Optometry and Vision Science and Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia, and ²School of Early Childhood and Inclusive Education, Queensland University of Technology, Brisbane, Australia

Citation information: Wood JM, Black AA, Hopkins S & White SJ. Vision and academic performance in primary school children. *Ophthalmic Physiol Opt* 2018; 38: 516–524. <https://doi.org/10.1111/opo.12582>

Keywords: academic achievement, children's vision, eye movements, vision screening, visual information processing

Correspondence: Joanne M Wood
E-mail address: j.wood@qut.edu.au

Received: 1 March 2018; Accepted: 9 August 2018; Published Online: 16 September 2018

Abstract

Purpose: Vision is considered important for academic performance in children; however, the evidence in this area tends to be inconsistent and inconclusive. This study explored the association between vision function and visual information processing measures and standardised academic achievement scores in Grade 3 Australian children.

Methods: Participants included 108 Grade 3 primary school children ($M = 8.82 \pm 0.32$ years) from three state primary schools in South-East Queensland. All participants underwent a standard vision screening, including distance visual acuity (VA), binocular vision testing and stereoacuity (SA). A computer-based battery of visual information processing tests including the Development Eye Movement (DEM) test, Visual Sequential Memory (VSM) and Symbol Search (SS) was also administered. Australian National Assessment Program for Literacy and Numeracy (NAPLAN) scores across five subtests of academic performance were obtained for each child: Reading, Writing, Spelling, Grammar/Punctuation and Numeracy.

Results: The DEM adjusted horizontal and vertical times were most strongly associated with all of the NAPLAN subtest scores ($p < 0.01$), adjusted for age and the socio-economic status of the school; the DEM ratio was not significantly associated with any of the NAPLAN subtests. VSM and SS scores were significantly associated with one or more NAPLAN subtests, as were worse and better eye VA; SA showed no significant association with any of the NAPLAN subtests.

Conclusions: Performance on the horizontal and vertical DEM subtests was most strongly associated with academic performance. These data, in conjunction with other clinical data, can provide useful information to clinicians regarding their prescribing and management philosophy for children with lower levels of uncorrected refractive error and binocular vision anomalies.

Introduction

A relatively large proportion (up to 40%) of school-aged children have visual problems that may affect their visual function.¹ Importantly, not all of these visual problems result in a reduction in visual acuity. For example, hyperopia does not tend to reduce visual acuity in children until levels are typically higher than 2.00 D,² and therefore may remain undetected by traditional vision screening techniques that typically focus on assessment of high contrast distance visual acuity and ocular alignment.³ The fact that many visual anomalies may go undetected in school-aged

children is highly relevant, given that good vision is believed to have an important role in school and academic-related performance.^{4–7} This has implications beyond the school years, as there is strong evidence that academic performance and educational attainment influence long-term health, economic and social outcomes.^{8,9}

A number of visual factors have been purported to be associated with learning-related problems and academic achievement. These include standard aspects of visual function including reduced visual acuity;^{10–12} uncorrected refractive errors,¹³ particularly hyperopia;^{14–16} binocular vision problems, including poor accommodative

facility,^{17–19} and stereoacuity.^{16,18} Poorly developed visual information processing skills, which refer to the cognitive abilities required to extract and organise visual input derived from the environment, have also been associated with poorer learning outcomes.^{12,20} Studies have shown that visual motor integration,^{12,21} reading eye movements,¹⁷ rapid automatised naming (RAN),²² visual spatial memory^{23–27} and visual information processing speed and search²⁸ are related to reading ability and other aspects of academic achievement, including numeracy. However, there are gaps remaining in the evidence linking standard measures of visual function and visual information processing skills with academic performance. These are largely because the definitions of ‘poor reading’ or ‘reduced academic performance’ are inconsistent between studies and many are based on non-standardised tests, as well as the fact that there has been a lack of research that has addressed whether the associations between reduced visual function and academic performance have a causative pathway. This lack of conclusive data indicating how, and at what level of severity, these visual anomalies impact on a child’s academic performance has led to widespread inconsistencies regarding the strategies adopted to clinically manage common non-amblyogenic visual problems in children, such as low to moderate levels of uncorrected refractive error and non-strabismic binocular vision anomalies.

The current study explored the association between standardised national academic achievement outcomes for literacy and numeracy performance on standard vision tests included in vision screening, and a range of tests of visual information processing in a cohort of Grade 3 Australian children (aged 8–9 years). We hypothesised that reductions in visual information processing and visual acuity would be associated with poorer performance on the standardised measures of academic outcomes. This study formed part of a larger study exploring the role of vision and eye movements in academic achievement, which recently demonstrated that those children who failed a standard vision screening assessment demonstrated significantly worse performance on measures of academic achievement than those who passed the vision screening.²⁹

Methods

Participants

Grade 3 children were recruited from three state primary schools from the outer metropolitan region of Brisbane, Australia. All three participating schools had Index of Community Socio-Economic Advantage (ICSEA) values between 940 and 986; all below the national mean of 1000. The ICSEA values are derived

from both community-level (remoteness and percent Indigenous enrolment) and child-level (parent occupation and education) data, and were used to enable comparison of academic performance between schools with similar children enrolled.

All procedures in this research were conducted in accordance with the ethical standards of the institutional and national research committees. The study was approved by the University Human Research Ethics Committee, which operates within the Australian National Statement on Ethical Conduct in Human Research. Approval to conduct research in Queensland State Schools was granted by the Queensland Government, Department of Education and Training.

Vision screening

Each child underwent a vision screening performed by final year optometry postgraduate students under the close supervision of an experienced paediatric optometrist; retinoscopy, cover test and ocular health assessment were undertaken by both the optometry students and the supervising paediatric optometrist. The screening battery selected was based on those used in Australia and is also typical of vision screening batteries adopted worldwide.³ These batteries are designed to screen for reduced visual acuity, significant refractive error, strabismus and other amblyogenic risk factors and include tests that can be undertaken by eye care providers (optometrists or orthoptists), but are more often undertaken by other health workers, such as trained nurses, who play a large role in school-based screenings in Australia.³

A brief case history was obtained to document any relevant ocular symptoms. The following vision tests were performed as part of the screening battery: distance visual acuity (VA) in each eye using a standard logMAR letter chart at three metres; distance VA through plus (+1.50 D) lenses to test for hyperopia; retinoscopy (for children who had a distance VA of 6/9 or worse, or greater than one line difference in distance VA or who were considered to have failed the plus lens hyperopia test if they achieved a distance VA of 6/9 or better through the lens); colour vision assessment (Ishihara test); and binocular vision screening (including assessment of near stereoacuity (SA) using the Stereo Fly and Graded circle test and screening for the presence of strabismus or significant heterophoria using a distance and near cover test). The magnitude of heterophoria was quantified using a Howell Dwyer Card. An ocular health assessment through direct ophthalmoscopy and pupil assessment were also undertaken. All vision tests were undertaken with a child’s existing spectacles, if used in the classroom.

Additionally, a computer-based battery of visual processing-related tests that have been previously reported to be linked with aspects of academic performance

including literacy and numeracy was administered including tests of visual memory, visual search, and a measure of rapid automatised naming (RAN) and reading-related eye movements. Computer-based versions of the tests were used to allow eye movements to be measured while children completed the tests using a Tobii TX300 system (www.tobiiipro.com); the results of these analyses will be reported separately. The visual processing tests were presented on a 23-inch computer screen at a working distance of 60 cm, with dimensions scaled to be as similar as possible to the original paper-based versions of the tests. As for the paper-based versions of the tests, children were required to provide their responses verbally to the examiner.

Visual information processing assessment

Visual sequential memory

A computer-based version of the test was adapted from the Visual Sequential Memory (VSM) subtest of the Test of Visual Perceptual Skills.^{30,31} The test evaluates short-term memory through assessing the ability to recognise a series of shapes, retain that pattern in memory, and immediately match it with the exact pattern from a group of four choices. Each of the shapes subtended 1.24° at the working distance of 60 cm (resolution of 6/90 Snellen equivalent), with the number of shapes in the sequence increasing progressively from 2 to 9, with participants being given gradually longer periods to view and encode the sequence as the difficulty level increased. The time to view the sequence begins at 5 s for 2–3 shapes and increases to 14 s for 8–9 shapes, with a maximum possible score of 16.

Symbol search

A computer-based test was used which was based upon the Symbol Search (SS) processing speed subtest of The Wechsler Intelligence Scale for Children - Australian Standardised Edition (WISC-IV). This test has been widely used for assessing the intellectual ability of children aged 6–16 years old³² and has been included in previous studies linking vision and academic-related performance.^{33–35} The SS test is a measure of perceptual discrimination, speed, accuracy, visual scanning and visual motor coordination. A horizontal array of symbols was presented, each symbol subtended 1.05° at the working distance of 60 cm, (resolution of 6/76 Snellen equivalent), which were divided into a target group on the left and a search group on the right. Participants were instructed to scan the two groups and indicate whether the target symbols (on the left) appeared in the search group (on the right); they were required to complete as many items as possible within 120 s. The number of correct responses was recorded. The maximum possible score is 60.

Developmental eye movement (DEM) test

A computer-based adaptation of the Developmental Eye Movement (DEM) test was selected given that scores on the DEM have been shown to be significantly associated with reading ability and visual processing in visually normal children³⁶ and in those with dyslexia.³⁷ However, the DEM outcome measures have not been shown to be significantly associated with saccadic eye movement skills as measured using standard eye movement tests,^{36,38} or with symptoms related to oculomotor dysfunction.³⁶

The DEM test consists of a pre-test; two vertical subtests with 40 numbers arranged in two columns (subtests A and B); and a horizontal subtest with 16 rows consisting of 80 irregularly spaced numbers (subtest C), which are the same numbers as those in subtests A and B combined. Each number subtended 0.48° vertically and 0.29° horizontally (resolution of 6/35 and 6/21 Snellen equivalents respectively). The vertical subtest is purported to measure rapid automatised naming (RAN) ability, the horizontal time measures RAN and oculomotor control, while the ratio of horizontal to vertical subtest times (after adjustment for errors), has been suggested to provide a measure of oculomotor control, by controlling for RAN.³⁹ In line with standard administration procedures, participants were asked to read the single digit numbers aloud as quickly and accurately as possible. The times taken to complete the two vertical columns and 16 horizontal lines were separately recorded. The horizontal and vertical test times were adjusted for errors in reporting the numbers, and a ratio of the adjusted horizontal over adjusted vertical time was calculated. In clinical practice, the raw vertical subtest is typically used rather than adjusted vertical time when calculating the ratio. The adjusted time is likely to be a better measure of performance as it accounts for naming errors and has been used in previous research studies;³⁸ analysis using raw vertical scores demonstrated similar associations with academic performance to those with the adjusted vertical time.

Academic achievement

Scaled achievement scores were obtained from the National Assessment Program for Literacy and Numeracy (NAPLAN), which comprises a series of five standardised subtests that are completed by all Australian children in Grades 3, 5, 7 and 9 and administered in a pen and paper format. Participants completed all Grade 3 NAPLAN subtests: Reading, Writing, Spelling, Grammar/Punctuation and Numeracy, which were administered in four testing sessions, over two consecutive days. Testing sessions were around 45 min in duration, formally administered in each school, with the scoring completed independently by the test administration authority in each state. Children's

results are given as scaled scores which range from 0 to 1000, with corresponding bands 1–10, which indicate how children perform compared to established national curriculum standards, mapped across Grade 3 to Grade 9. Children in this study completed the Grade 3 NAPLAN subtests, which are reported to have good internal reliability (Reading $\alpha = 0.88$; Writing $\alpha = 0.96$; Spelling $\alpha = 0.92$; Grammar/Punctuation $\alpha = 0.79$; and Numeracy $\alpha = 0.86$).⁴⁰ The NAPLAN assessments were completed in May, approximately 4 months prior to the vision screening and testing.

Data analysis

All statistical analyses were completed using IBM SPSS software version 23.0 (www.ibm.com/spss). Descriptive statistics were used to describe the visual function measures and NAPLAN performance across all subtests (Reading, Writing, Spelling, Grammar/Punctuation and Numeracy). Pearson correlations were used to explore the relationships between the standard vision measures of VA and SA and the visual information processing measures of DEM, SS and VSM. Linear regression models were conducted to examine the associations between the various visual function and visual information processing measures and each of the NAPLAN test scores separately with adjustment for potential covariates of ICSEA values and age.

Results

Of the 119 Grade 3 children who were screened for inclusion in the study, 108 children (mean age: 8.82 ± 0.32 years; range: 8.17–9.67 years; 61 females; 47 males) completed all aspects of testing and formed the sample included in this analysis. The remaining 11 children were excluded because they failed to complete the NAPLAN tests ($n = 10$) or failed to complete all of the computer-based vision assessments ($n = 1$).

The visual characteristics of the participants are presented in Table 1. Fifteen children had VA of 6/9 or below (VA worse eye of 0.2 logMAR or more) and were all identified as having uncorrected refractive error. All of the children with VA of 6/9 or below had good ocular alignment (no strabismus detected with cover test) and their horizontal heterophoria findings were within normal limits at distance and near; that is between 1Δ exophoria and 2.5Δ esophoria at distance, and between 6.5Δ exophoria and 2Δ esophoria at near.^{41,42} Note that the scores on the VSM and SS are presented in their raw forms, rather than the scaled scores, which were developed from the paper-based version of the test. The values for the horizontal and vertical adjusted times for the DEM are also presented as

raw rather than age-adjusted data given the latter is based on paper-based presentation of the test.

Significant correlations were evident between the standard vision measures of worse and better eye VA with VSM and the horizontal and vertical DEM times, with r values ranging between 0.195 and -0.313 ($p < 0.01$). The strongest association was between better eye VA and VSM ($r = -0.313$, $p = 0.001$). Log SA was only significantly associated with VSM ($r = -0.248$; $p < 0.01$) and horizontal DEM time ($r = -0.214$; $p < 0.05$). None of the standard vision measures were significantly correlated with performance on the SS test.

In terms of academic performance, the group mean NAPLAN scores were 395 ± 94 (Reading), 381 ± 61 (Writing), 393 ± 94 (Spelling), 400 ± 93 (Grammar/Punctuation) and 384 ± 78 (Numeracy). Children’s mean scores in all five NAPLAN subtests were below the national means, but were within a similar range to that of schools with comparable ICSEA levels.²⁹

Linear regression models, adjusting for age and ICSEA, showed a number of significant associations between the standard VA tests and NAPLAN scores (Table 2). Notably, worse eye VA showed the strongest associations, where poorer NAPLAN performance was associated with reduced worse eye VA, however, these associations were limited to the Grammar/Punctuation and Numeracy subtests ($p < 0.05$). Reduced better eye VA was significantly associated with poorer Numeracy scores ($p = 0.021$), while SA showed no significant associations with any of the NAPLAN subtests.

Of the visual processing measures, the horizontal and vertical adjusted DEM times showed the strongest associations with all of the NAPLAN subtests ($p < 0.01$), with longer DEM times being associated with poorer NAPLAN scores. However, the DEM ratio was not significantly

Table 1. Group mean scores for the standard vision and vision-related tests

	Mean (S.D.)	Range
Better eye habitual visual acuity (logMAR)	-0.01 (0.12)	-0.14 to 0.60
Worse eye habitual visual acuity (logMAR)	+0.02 (0.15)	-0.14 to 0.82
Log stereoacuity (log sec arc)	1.74 (0.25)	1.30 to 3.56
Visual sequential memory (number correct out of 16)	10.91 (3.71)	0 to 16
Symbol search (number correct in 120 s)	24.33 (4.71)	13 to 38
DEM: vertical adjusted time (s)	58.14 (16.43)	34.80 to 143.80
DEM: horizontal adjusted time (s)	73.28 (21.16)	39.50 to 182.20
DEM: ratio	1.27 (0.20)	0.85 to 1.91

Table 2. Association between vision measures and NAPLAN scores: linear regression standardised beta coefficients (p values) adjusted for age and ICSEA values

	NAPLAN Scaled Scores [standardised beta coefficients (p values)]				
	Reading	Writing	Spelling	Grammar/Punctuation	Numeracy
Better eye VA (logMAR)	-0.096 (0.33)	-0.083 (0.40)	-0.121 (0.22)	-0.171 (0.09)	-0.226 (0.021)*
Worse eye VA (logMAR)	-0.186 (0.06)	-0.112 (0.27)	-0.179 (0.07)	-0.243 (0.015)*	-0.264 (0.008)**
Log stereoacuity	0.008 (0.94)	-0.133 (0.17)	0.065 (0.50)	-0.063 (0.52)	-0.160 (0.10)
DEM: horizontal adjusted time	-0.347 (<0.001)**	-0.284 (0.003)**	-0.380 (<0.001)**	-0.303 (0.002)**	-0.343 (<0.001)**
DEM: vertical adjusted time	-0.328 (0.001)**	-0.304 (0.002)**	-0.388 (<0.001)**	-0.337 (<0.001)**	-0.290 (0.003)**
DEM: ratio	-0.076 (0.44)	0.011 (0.91)	0.060 (0.54)	-0.005 (0.96)	-0.148 (0.13)
Symbol search	0.161 (0.10)	0.147 (0.13)	0.242 (0.011)*	0.233 (0.016)*	0.213 (0.027)*
Visual sequential memory	0.077 (0.43)	0.168 (0.08)	0.072 (0.471)	0.145 (0.14)	0.254 (0.008)**

* $p < 0.05$; ** $p < 0.01$.

associated with any NAPLAN subtest ($p > 0.13$). Symbol search scores were also significantly associated with the Spelling, Grammar/Punctuation and Numeracy subtests ($p < 0.05$), while the VSM was only significantly associated with the Numeracy subtest ($p < 0.01$) but to a lesser extent than for the DEM adjusted times. Receiver operating characteristic (ROC) analyses were used to further explore the ability of the DEM horizontal and vertical adjusted times to discriminate between children whose academic performance scores were below the national minimum standard, compared to those at or above the national minimum standard. These ROC curves were generated for each of the five NAPLAN subtests adjusted for age and ICSEA. The area under the curves (AUC) were significant in all of the models for the DEM horizontal adjusted time [range 0.72 (Numeracy) to 0.79 (Grammar/Punctuation)], and for the DEM vertical adjusted time [range 0.74 (Reading) to 0.82 (Spelling)].

To explore whether these associations between the DEM measures and NAPLAN performance were independent of visual function assessed with the standard vision measures, the models were also adjusted for worse eye VA, as it was associated with two of the NAPLAN subtests. These analyses demonstrated that the associations between both the adjusted horizontal and adjusted vertical DEM times with all of the NAPLAN subtests remained significant, independent of visual function.

Discussion

In this study, we demonstrated significant associations between visual information processing test performance and scores on national standardised academic achievement tests across a range of subtests including Reading, Writing, Spelling, Grammar/Punctuation and Numeracy, in a sample of children in one grade level of school. DEM adjusted vertical and horizontal times demonstrated highly

significant associations with all of the NAPLAN subtests, in both the linear regression and ROC analyses, even after adjusting for the child's age and the ICSEA level of the school attended. There were inconsistent associations between the standard vision measures and NAPLAN performance. Worse eye VA demonstrated some significant associations with academic outcomes, yet only for the Numeracy and Grammar/Punctuation scores. None of the vision screening tests employed in this study were significantly associated with the Reading, Writing or Spelling academic outcomes.

The finding that the DEM adjusted vertical and horizontal times were significantly associated with the various academic outcome measures is likely to reflect their slower reading rates in general, negatively affecting performance on timed tasks that are typical of most formal school assessments. Indeed, even numeracy tests require children to read the questions before they can answer them. The horizontal adjusted DEM time was always the measure most strongly associated with the academic outcomes, even when adjusted for visual function (worse eye VA). Our finding that the horizontal adjusted time was most strongly associated with the academic outcomes, (albeit explaining only 14% of the variance in NAPLAN scores), is in support of the findings of Ayton *et al.*,³⁶ who reported the strongest correlations between the DEM horizontal subtest and Burt reading test raw scores in their sample of children, aged 8–11 years.

The DEM ratio, which has been purported to provide a measure of reading-related saccadic eye movement performance independent of RAN,³⁹ was not significantly associated with any of the NAPLAN academic measures in the current study. This lack of association could not be explained by a lack of variation in performance in the group, which ranged from 0.85 to 1.91, suggesting that a number of children within the sample had oculomotor dysfunction when compared to samples of similar age.⁴³ While

other studies have reported significant relationships between the DEM ratio and reading outcomes,^{36,39} they also noted that the associations were stronger for the horizontal and vertical times. Furthermore, the horizontal and vertical DEM times have shown better repeatability than the ratio,⁴⁴ which may explain their stronger associations with academic outcomes in the present study.

Importantly, while our findings demonstrate that slower horizontal and vertical DEM times are associated with lower levels of academic performance (including reading and other core academic skills) we cannot conclude a causative relationship, given the cross-sectional nature of this study. Indeed, it has been suggested that abnormal DEM performance in poor readers is likely to be because poor readers lack practice in reading, rather than eye movement difficulties being reflected in DEM scores causing reading difficulties.⁴⁵ A lack of association between abnormal eye movements and delayed reading skills has also been shown in more recent studies,⁴⁶ highlighting the likelihood that the DEM taps into other factors that link with academic performance, other than eye movement skills.

The other measures of visual information processing, including SS and VSM were both significantly associated with the NAPLAN numeracy scores, with the SS being associated with Spelling, Grammar/Punctuation and Numeracy Scores but not Reading or Writing, although these associations were lower than those of the vertical and horizontal times of the DEM. Our finding that VSM was significantly associated with the numeracy NAPLAN subtest is in support of previous findings suggesting that visual spatial memory is associated with mathematical abilities,^{22,26,47} although Kulp *et al.*²⁶ also found an association with reading ability. In a large scale study, Chen *et al.*¹² reported a significant relationship between three aspects of visual information processing skills (visual motor integration, visual spatial and visual analysis) and academic achievement based on school examination results. A higher failure rate for all aspects of visual information processing skills (including Visual Perceptual Skills, Gardner Reversal Frequency test and Wold Sentence Copying test) was observed among children with low academic performance. However, school-based examination results were used to categorise children into the respective achievement groups in this study, which may vary between schools and could potentially lead to bias, given that different criterion may be used to make those judgements across schools. In the current study, academic performance was assessed using national grading standards. Conversely, Goldstand *et al.*⁴⁸ found no association between visual information processing skills assessed with tests of visual motor integration and the motor-free visual perception test and reading performance. This negative finding may have been because the children in their

sample (Grade 7 students) were beyond the 'learning to read' stage. Indeed, it has been proposed that visual information processing skills play a more significant role in the learning process of younger children (kindergarten to Grade 2) in the 'learning to read' phase compared to older children.⁴⁹ This is also of relevance to the data collected in the current study, where the participants were in Grade 3 and therefore in the early stages of transitioning past the 'learning to read' stage.^{20,50}

Our findings demonstrate inconsistent associations between the standard vision tests and the tests of academic performance. Of the tests of VA, worse eye, rather than better eye VA, demonstrated the most significant associations with NAPLAN outcome measures, although the strength of these associations was only relatively low. For example, worse eye VA was more strongly associated with Numeracy scores than better eye VA, but explained only 7% of the variance in Numeracy scores. Interestingly, the associations were only significant for the subtests of Numeracy and Grammar/Punctuation, which may reflect the fact that resolution of small symbols is important in these tasks, whereas for reading and writing, for example, you may be able to get adequate sense (or gist) of the meaning of text even if a small amount of detail is missing.

These limited levels of association between VA and only some aspects of academic performance are likely to explain some of the inconsistencies in the previous literature in this area, where some studies have reported a relationship between VA and academic performance, while others have failed to find any association. Two studies of Grade 2 children reported significant associations between habitual distance VA and reading or academic ability.^{10,12} A more recent study of a large UK cohort of children aged 4–5 years also found that reduced VA was linked with reduced school literacy measured using the Woodcock Reading Mastery Tests-Revised subtest: letter identification.⁵¹ This is particularly relevant given that early literacy is a key indicator of future reading and educational ability.⁵² Conversely, other studies have failed to find any association between VA and reading and academic performance.^{46,53,54} However, while Helveston *et al.*⁵³ failed to find a relationship between visual acuity and reading ability in children from Grades 1 to 3, teachers' perceptions were used to categorise the children's reading ability. Dirani *et al.*⁵⁴ in a study of Singaporean children, also failed to find a relationship between academic performance as measured by nationwide examinations administered at the end of Grade 4 and visual acuity; however, this may be attributed to the limited variation in visual acuity within their sample (where the majority of children had VA better than 6/7.5).

Our study also failed to find a significant association between stereoacuity and any of the NAPLAN outcomes.

Some studies have reported links between reduced stereoacuity and reduced academic ability, measured using the Test of Preschool Early Literacy,¹⁶ Metropolitan Achievement Test,¹⁸ teacher graded reading, spelling and mathematics,⁵⁵ while other studies have failed to find any association.⁵³ It should be noted, however, that the lack of association in our study might have been because most children in the sample had relatively high levels of SA.

A major strength of the current study was that academic achievement was measured across a range of subtests including Reading, Writing, Spelling, Grammar/Punctuation and Numeracy, using national standardised achievement tests that were independently administered and scored. However, it is also acknowledged that the study was limited by its relatively small sample size of children ($n = 108$) from three schools in the South-East Queensland region. It is important that future studies include larger sample sizes of children from a wider range of schools, including more comprehensive visual information rather than data obtained from a vision screening examination. It is also acknowledged that the vision screening battery, like the majority of vision screening assessments worldwide, did not include tests of near visual acuity or accommodative function, although near visual function was investigated through stereoacuity and near heterophoria assessment. In addition, the refractive status of children was only assessed on those who failed the vision screening tests of distance VA or the plus lens test; hence, it is possible that low to moderate levels of hyperopia may have been missed. However, the focus of this study was not on the effect of refractive error on the association between vision and academic performance; and, our sample size precluded grouping our participants by refractive error. The cross-sectional nature of this study also precludes any conclusions about causative relationships; future studies should also include longitudinal assessment of children to determine how the association between vision and academic performance varies as they progress through the early school years.

Collectively, our findings in a cohort of Grade 3 children demonstrated that adjusted horizontal and to a lesser extent vertical times, as measured on the DEM, had the strongest associations with academic outcomes. This is the first study to demonstrate this relationship using national standardised academic measures across a range of subtests including Reading, Writing, Spelling, Grammar/Punctuation and Numeracy, and provides support for previously reported associations between the DEM, visual processing speeds and reading performance.³⁶ Our findings do not suggest a causative relationship between poor DEM results and poor reading outcomes. However, the DEM horizontal and vertical subtests could be used by clinicians in conjunction with other clinical data, to assist in guiding clinical management decisions, for example, whether or not to prescribe non-

amblyogenic hyperopic refractive errors or to treat non-strabismic binocular vision conditions.

Acknowledgements

Funding: This work was financially supported by the Ian Potter Foundation (Ref: 20140415).

Participants: Thank you to the schools, teachers, parents and children for their interest and involvement in this research.

Disclosure

The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

References

1. Junghans B, Kiely PM, Crewther DP & Crewther SG. Referral rates for a functional vision screening among a large cosmopolitan sample of Australian children. *Ophthalmic Physiol Opt* 2002; 22: 10–25.
2. Mutti DO. To emmetropize or not to emmetropize? The question for hyperopic development. *Optom Vis Sci* 2007; 84: 97–102.
3. Hopkins S, Sampson GP, Hendicott P & Wood JM. Review of guidelines for children's vision screenings. *Clin Exp Optom* 2013; 96: 443–449.
4. Borsting E & Rouse MW. Detecting learning-related visual problems in the primary care setting. *Optometry* 1994; 65: 642–650.
5. American Optometric Association. *Optometric clinical practice guideline. Care of patient with learning related vision problems*. 2008. <http://www.aoa.org/documents/optometrists/CPG-20.pdf> (Accessed 14/09/13).
6. Garzia RP. The relationship between visual efficiency problems and learning. In: *Optometric Management of Learning-Related Vision Problems*, Scheiman M & Rouse M (eds). Mosby-Elsevier: St Louis, MO, 2006; pp. 209–235.
7. Ihekaire DE & Anyanwu C. Learning-related vision problems in school age children in Imo State University primary and secondary schools. *Int J Sci Res Ed* 2012; 5: 109–116.
8. Baker DP, Leon J, Smith Greenaway EG, Collins J & Movit M. The education effect on population health: a reassessment. *Popul Dev Rev* 2011; 37: 307–332.
9. Cassells R, Duncan A, Abello A, D'Souza G & Nepal B. *Smart Australians: Education and Innovation in Australia*. AMP: Melbourne, 2012.
10. O'Grady J. The relationship between vision and educational performance: a study of year 2 children in Tasmania. *Aust J Optom* 1984; 67: 126–140.

11. Ygge J, Lennerstrand G, Axelsson I & Rydberg A. Visual functions in a Swedish population of dyslexic and normally reading children. *Acta Ophthalmol* 1993; 71: 1–9.
12. Chen AH, Bleything W & Lim YY. Relating vision status to academic achievement among year-2 school children in Malaysia. *Optometry* 2011; 82: 267–273.
13. Grisham JD & Simons HD. Refractive error and the reading process: A literature analysis. *Optometry* 1986; 57: 44–55.
14. van Rijn LJ, Krijnen JSM, Nefkens-Molster AE, Wensing K, Gutker E & Knol DL. Spectacles may improve reading speed in children with hyperopia. *Optom Vis Sci* 2014; 91: 397–403.
15. Shankar S, Evans MA & Bobier WR. Hyperopia and emergent literacy of young children: Pilot study. *Optom Vis Sci* 2007; 84: 1031–1038.
16. Kulp MT, Ciner E, Maguire M et al. Uncorrected hyperopia and preschool early literacy: results of the vision in preschoolers-hyperopia in preschoolers (VIP-HIP) study. *Ophthalmology* 2016; 123: 681–689.
17. Kulp MT & Schmidt PP. Effect of oculomotor and other visual skills on reading performance: a literature review. *Optom Vis Sci* 1996; 73: 283–292.
18. Kulp MT & Schmidt PP. Visual predictors of reading performance in kindergarten and first grade children. *Optom Vis Sci* 1996; 73: 255–262.
19. Simons H & Grisham J. Binocular anomalies and reading problems. *Optometry* 1987; 58: 578–587.
20. Kavale K. Meta-analysis of the relationship between visual perceptual skills and reading achievement. *J Learn Disabil* 1982; 15: 42–51.
21. Kulp MT. Relationship between visual motor integration skill and academic performance in kindergarten through third grade. *Optom Vis Sci* 1999; 76: 159–163.
22. Geary DC. Cognitive predictors of achievement growth in mathematics: a 5-year longitudinal study. *Dev Psychol* 2011; 47: 1539–1552.
23. Lobier M, Dubois M & Valdois S. The role of visual processing speed in reading speed development. *PLoS One* 2013; 8: e58097.
24. Lyle JG. Performance of retarded readers on the Memory-For-Designs test. *Percept Mot Skills* 1968; 26: 851–854.
25. Barker BM. Interrelationships of perceptual modality, short-term memory and reading achievement. *Percept Mot Skills* 1976; 43: 771–774.
26. Kulp MT, Edwards KE & Mitchell GL. Is visual memory predictive of below-average academic achievement in second through fourth graders? *Optom Vis Sci* 2002; 79: 431–434.
27. Ciner EB. Management of refractive errors in infants, toddlers and preschool children. *Probl Optometry* 1990; 2: 394–419.
28. Fry AF & Hale S. Processing speed, working memory, and fluid intelligence: evidence for a developmental cascade. *Psychol Sci* 1996; 7: 237–241.
29. White SLJ, Wood JM, Black AA & Hopkins S. Vision screening outcomes of Grade 3 children in Australia: differences in academic achievement. *Int J Educ Res* 2017; 83: 154–159.
30. Martin NA. *Test of Visual Perceptual Skills*, 3rd edn. Academic Therapy Publications: Novato, CA, 2006.
31. Gardner MF. *Test of Visual Perceptual Skills (Non-Motor) - Revised*. Psychological and Educational Publications: San Francisco, CA, 1996.
32. Wechsler D. *Wechsler Intelligence Scale for Children—Fourth Edition: Australian Standardised Edition (WISC-IV Australian)*. Psychological Corporation: Sydney, 2005.
33. Narayanasamy S, Vincent SJ, Sampson GP & Wood JM. Impact of simulated hyperopia on academic-related performance in children. *Optom Vis Sci* 2015; 92: 227–236.
34. Narayanasamy S, Vincent SJ, Sampson GP & Wood JM. Simulated hyperopic anisometropia and reading, visual information processing, and reading-related eye movement performance in children. *Invest Ophthalmol Vis Sci* 2014; 55: 8015–8023.
35. Narayanasamy S, Vincent SJ, Sampson GP & Wood JM. Simulated astigmatism impairs academic-related performance in children. *Ophthalmic Physiol Opt* 2015; 35: 8–18.
36. Ayton LN, Abel LA, Fricke TR & McBrien NA. Developmental eye movement test: what is it really measuring? *Optom Vis Sci* 2009; 86: 722–730.
37. Northway N. Predicting the continued use of overlays in school children—a comparison of the Developmental Eye Movement test and the Rate of Reading test. *Ophthalmic Physiol Opt* 2003; 23: 457–464.
38. Webber A, Wood J, Gole G & Brown B. DEM test, visagraph eye movement recordings, and reading ability in children. *Optom Vis Sci* 2011; 88: 295–302.
39. Garzia RP, Richman JE, Nicholson SB & Gaines CS. A new visual-verbal saccade test: the development eye movement test (DEM). *Optometry* 1990; 61: 124–135.
40. Australian Curriculum AARA. *National Assessment Program – Literacy and Numeracy 2014: Technical Report*. ACARA: Sydney, 2015. https://www.nap.edu.au/_resources/2014_NAPLAN_technical_report.pdf (Accessed 26/02/18).
41. Wong EP, Fricke TR & Dinardo C. Interexaminer repeatability of a new, modified prentice card compared with established phoria tests. *Optom Vis Sci* 2002; 79: 370–375.
42. Jimenez R, Perez MA, Garcia JA & Gonzalez MD. Statistical normal values of visual parameters that characterize binocular function in children. *Ophthalmic Physiol Opt* 2004; 24: 528–542.
43. Xie Y, Shi C, Tong M et al. Developmental Eye Movement (DEM) test norms for Mandarin Chinese-speaking children. *PLoS One* 2016; 11: e0148481.
44. Orlansky G, Hopkins KB, Mitchell GL et al. Reliability of the developmental eye movement test. *Optom Vis Sci* 2011; 88: 1507–1519.
45. Medland C, Walter H & Woodhouse JM. Eye movements and poor reading: does the Developmental Eye Movement test measure cause or effect? *Ophthalmic Physiol Opt* 2010; 30: 740–747.

46. Vinuela-Navarro V, Erichsen JT, Williams C & Woodhouse JM. Saccades and fixations in children with delayed reading skills. *Ophthalmic Physiol Opt* 2017; 37: 531–541.
47. Dumontheil I & Klingberg T. Brain activity during a visuospatial working memory task predicts arithmetical performance 2 years later. *Cereb Cortex* 2012; 22: 1078–1085.
48. Goldstand S, Koslowe KC & Parush S. Vision, visual-information processing, and academic performance among seventh-grade schoolchildren: a more significant relationship than we thought? *Am J Occup Ther* 2005; 59: 377–389.
49. Flax N. The relationship between vision and learning: general issues. In: *Optometric Management of Learning-Related Vision Problems*, Scheiman M & Rouse M (eds). Mosby-Elsevier: St Louis, MO, 2006; pp. 183–206.
50. Solan HA & Mozlin R. The correlations of perceptual-motor maturation to readiness and reading in kindergarten and the primary grades. *Optometry* 1986; 57: 28–35.
51. Bruce A, Fairley L, Chambers B, Wright J & Sheldon TA. Impact of visual acuity on developing literacy at age 4–5 years: a cohort-nested cross-sectional study. *BMJ Open* 2016; 6: e010434.
52. Marchman VA & Fernald A. Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. *Dev Sci* 2008; 11: F9–F16.
53. Helveston E, Weber J, Miller K *et al.* Visual function and academic performance. *Am J Ophthalmol* 1985; 99: 346–355.
54. Dirani M, Zhang X, Goh LK, Young TL, Lee P & Saw SM. The role of vision in academic school performance. *Ophthalmic Epidemiol* 2010; 17: 18–24.
55. Kulp M & Schmidt P. A pilot study. Depth perception and near stereoacuity: is it related to academic performance in young children? *Binocul Vis Strabismus Q* 2002; 17: 129–134.