Accepted for publication in Ophthalmic and Physiological Optics (9/8/18)

Running Head: Vision and Academic Performance in Children

Vision and academic performance in primary school children

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

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

**Methods:** Participants included 108 Grade 3 primary school children (M=8.82 ± 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 (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 only some of the NAPLAN subtests, as were worse and better eye VA; SA showed no significant association with NAPLAN subtests.

**Conclusions:** Performance on the horizontal and vertical DEM subtests was most strongly associated with academic performance scores. This suggests the potential for these measures to be used clinically for identifying children at risk for low academic achievement, enabling appropriate targeting of early visual interventions, such as correction of lower levels of uncorrected refractive error and binocular vision anomalies.

**Keywords:** visual information processing, eye movements, academic achievement; vision screening, children's vision
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 impact on 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.\(^18\) 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 automated naming (RAN),\(^22\) visual spatial memory\(^23\)-\(^27\) and visual information processing speed and search\(^28\) 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, largely because the definitions of ‘poor reading’ or ‘reduced academic performance’ are inconsistent between studies and many are based on non-
standardised tests. 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 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 committee. The study was approved by 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. The screening battery selected was based on those used in Australia and is also typical of vision screening batteries adopted worldwide. 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 (+1.50D) 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), binocular vision screening (including assessment of near stereoacuity (SA) using a Titmus stereotest 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 was 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. These 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.

**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 to 16 years old and has been included in previous studies linking vision and academic-related performance. 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 60cm, (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 seconds. 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 children and in those with dyslexia. 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, or with symptoms related to oculomotor dysfunction.

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 automated 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. 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 sixteen 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. While 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 as per previous studies; 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 minutes 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 and punctuation $\alpha = 0.79$; and numeracy $\alpha = 0.86$). The NAPLAN assessments were completed in May, approximately four months prior to the vision screening.

**Data analysis**

All statistical analyses were completed using SPSS (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: $8.82 \pm 0.32$ years; range: 8.17 to 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. 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.

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

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Better Eye Habitual Visual Acuity (logMAR)</td>
<td>-0.01 (0.12)</td>
<td>-0.14 - 0.60</td>
</tr>
<tr>
<td>Worse Eye Habitual Visual Acuity (logMAR)</td>
<td>+0.02 (0.15)</td>
<td>-0.14 - 0.82</td>
</tr>
<tr>
<td>Log Stereoacuity (log sec arc)</td>
<td>1.74 (0.25)</td>
<td>1.30 - 3.54</td>
</tr>
<tr>
<td>Visual Sequential Memory (number correct out of 16)</td>
<td>10.91 (3.71)</td>
<td>0 - 16</td>
</tr>
<tr>
<td>Symbol Search (number correct in 120s)</td>
<td>24.33 (4.71)</td>
<td>13 - 38</td>
</tr>
<tr>
<td>DEM: vertical adjusted time (s)</td>
<td>58.14 (16.43)</td>
<td>34.80 -143.80</td>
</tr>
<tr>
<td>DEM: horizontal adjusted time (s)</td>
<td>73.28 (21.16)</td>
<td>39.50 - 182.20</td>
</tr>
<tr>
<td>DEM: ratio</td>
<td>1.27 (0.20)</td>
<td>0.85 – 1.91</td>
</tr>
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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.  

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 significant 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 associated with any NAPLAN subtest (p>0.13). Symbol search scores were 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). 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 scores remained significant, independent of visual function.
<table>
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<tr>
<th>Table 2. Association between visual processing measures and NAPLAN scores: linear regression standardised beta coefficients (p values) adjusted for age and ICSEA values</th>
</tr>
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<tr>
<td><strong>NAPLAN Scaled Scores</strong> (standardised beta coefficients (p values))</td>
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<tr>
<td></td>
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<tr>
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*p<0.05; **p<0.01
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 large 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, 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 to 11 years.
The DEM ratio, which has been purported to provide a measure of reading-related saccadic eye movement performance independent of RAN,\textsuperscript{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 – 1.91, suggesting that a number of children within the sample had oculomotor dysfunction when compared to samples of similar age.\textsuperscript{41} While other studies have reported significant relationships between the DEM ratio and reading outcomes,\textsuperscript{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,\textsuperscript{42} 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.\textsuperscript{43} A lack of association between abnormal eye movements and delayed reading skills has also been shown in more recent studies,\textsuperscript{44} 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 Symbol Search and Visual Sequential Memory were significantly associated with some but not all of the NAPLAN subtests, although these associations were lower than those of the vertical and horizontal times of the DEM. Our finding that visual sequential memory was significantly associated with the
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 score 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.\textsuperscript{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.\textsuperscript{49} This is particularly
relevant given that early literacy is a key indicator of future reading and educational ability.\textsuperscript{50}
Conversely, other studies have failed to find any association between VA and reading and
academic performance.\textsuperscript{44, 51, 52} However, while Helveston et al\textsuperscript{51} 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\textsuperscript{52} 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 Metropolitan Achievement Test\(^1\)\(^8\) and teacher graded reading, spelling and mathematics,\(^5\)\(^3\) while other studies have failed to find any association.\(^5\)\(^1\) It should be noted, however, that the lack of association in our study may 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. While our findings do not suggest a causative relationship between poor DEM results and poor reading outcomes, the DEM horizontal and vertical subtests could be used by clinicians to identify those children who are potentially at risk of reduced academic performance and assist in guiding clinical management decisions regarding 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.

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