Amblyopia, or ‘lazy eye’, is the most common ophthalmological condition affecting children, with a prevalence of approximately 1–5%.1–3 It arises from abnormal visual development during childhood, a process occurring competitively between fellow eyes, and can be due to strabismus, refractive error (especially anisometropia, a difference in the refractive state between fellow eyes), or ‘pattern deprivation’ (visual impairment due to structural eye abnormalities).3 Amblyopia typically manifests as reduced visual acuity (VA) in one eye and can lead to issues later in life, such as limitation of occupational choices and visual impairment if something happens to the better-seeing eye.4,5 Amblyopia treatment is partly effective so long as it occurs before the critical period of child visual development (about seven to nine years of age),6,7 and so many countries have some form of screening to detect amblyopia while it is still amenable to treatment.6–10

In 2008, a nationwide screening programme was introduced in New Zealand, the B4 School Check (B4SC), which includes vision screening. Vision screening is performed by vision-hearing technicians (VHT) who aim to test all four-year-old children in New Zealand. The current B4SC protocol assesses the VA of each eye using letter matching with the Parr Vision chart with confusion bars at four metres (this is the same as the Sheridan-Gardener chart which is used at six metres).11 Testing is typically performed at the child’s educational or day-care facility. Failure of the child to pass the B4SC vision screening, defined as VA of 6/12 or worse in one or both eyes, results in referral to either a community optometrist, private ophthalmologist or district health board (DHB) eye clinic at the discretion of the child’s parent/caregiver. A VA of 6/9 in one eye and 6/6 in the other results in rescreening, and a VA of 6/9 or in both eyes (ie, no difference between the eyes) results in...

**ABSTRACT**

**AIMS:** To assess the accuracy of the B4 School Check (B4SC) vision screening programme in two distinct regions of New Zealand.

**METHODS:** A retrospective audit of all children who were screened for vision in the Southern and Tairawhiti District Health Boards, between 1 April and 30 September 2016. Results from the B4SC screening programme (n=2,109) were compared to records for all children who were screened and subsequently presented to an optometrist at a DHB eye clinic (n=116).

**RESULTS:** The B4SC produced a sensitivity in the range of 54.7% to 94.7% and a specificity of 93.8% to 95.7%. There was a low positive predictive value (PPV), between 29.5% and 51.1%, with a relatively high number of false positive referrals. The negative predictive value (NPV) was higher, however, between 97.8% and 99.7%, meaning nearly all children who passed screening had no visual impairment.

**CONCLUSIONS:** The high NPV is reassuring that very few children with visual impairment are missed by screening. The low PPV was consistent with the international literature and is related to a tendency for over-referral from the B4SC programme. Further work could evaluate increasing the threshold for referral to reduce the number of false positive cases.

**ARTICLE**
in a pass. If on rescreening, the VA remains at 6/9 in one eye and 6/6 in the other, or becomes worse in either eye, the child is referred.12

Currently, there is little published data regarding the performance of this screening programme. Therefore, the primary aim of this study was to assess the accuracy of the B4SC vision screening programme in terms of sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV), in two distinct regions in New Zealand, as well as to assess how VA measurement by VHTs compare to optometrists or DHB eye-clinic assessment.

Methods

This study was a retrospective audit of all children who were screened for vision between 1 April 2016 and 30 September 2016, in the B4SC programme, in two distinct New Zealand DHBs: Southern (SDHB) and Tairawhiti (TDHB), potentially allowing identification of differences in screening throughout New Zealand.

The SDHB catchment area is comprised of the southern half of the South Island of New Zealand, and has a population of about 320,000, 10% of whom are New Zealand Māori. The TDHB catchment area is comprised of Gisborne and the East Cape of the North Island of New Zealand, and has a population of about 48,000, 50% of whom are New Zealand Māori. The SDHB is relatively less deprived compared with the national average, whereas the TDHB is relatively more deprived.13

Data for this study were obtained from three sources: New Zealand Ministry of Health (MoH) B4SC Database, Southern and Tairawhiti DHb eye clinic records, and community optometrists located within the Southern and Tairawhiti DHb regions. Identifying details of the children from each source was used to cross-match screening results of children to any results from follow-up eye-care. Crossmatched cases were then de-identified.

The Ministry of Health Database

Screening information for every child who was screened for vision in Southern and Tairawhiti DHBs within the study period was obtained from the MoH, and the following was collected: identifying information (ie, name, date of birth and NHI number), date of screening, ethnicity, sex, unaided visual acuity of right and left eyes obtained through screening, and referral outcome from screening (ie, pass, referral or rescreen).

Southern and Tairawhiti DHb Eye Clinic Data

Identifying details for all children aged four to seven years (a window maximising identification of children who could have theoretically been screened within the study period) who had been seen at a Southern DHb eye clinic (Dunedin Hospital or Invercargill Hospital) or a Tairawhiti DHb eye clinic (Gisborne Hospital) between 1 April and 30 November 2016 were obtained retrospectively. This longer data collection period allowed for delay between VHT referral and first specialist assessment at an eye clinic. Identifying details were used to crossmatch children to the MoH Database.

Every child who presented to a Southern or Tairawhiti DHb eye clinic, and who was also screened between 1 April and 30 September 2016 (regardless of their screening outcome) was de-identified and the following additional clinical information from the patient notes was recorded: unaided and best-corrected (as applicable) visual acuities of right and left eyes, the visual acuity test used, cause of visual impairment (if any), opthalmic examination findings including cycloplegic refraction (if performed) or ocular pathology, and management (glasses, penalisation therapy, surgery, observation or discharge).

Community optometrist clinical data

We approached all local community optometrists within the Southern DHb and Tairawhiti DHb catchment regions for their voluntary provision of clinical records. Identifying details of all children aged four to seven years seeing an optometrist between 1 April and 31 October 2016 was recorded by each optometry practice. Again, this longer data collection period allowed for delay between referral and optometry assessment.

Identifying details of every child who was reported as having attended a community optometry practice was cross-matched to the MoH Database.
The same clinical data was collected for every child who presented to a community optometrist and was also on the MoH Database (regardless of screening outcome), as for children seen at DHB clinics.

Data analysis
Sensitivity, specificity, PPV and NPV were estimated for pooled data. The study cohort consisted of children screened who voluntarily presented to an eye healthcare professional, meaning it was not a sample representative of all children undergoing screening. Therefore, the calculation was performed using a ‘best-case, worse-case’ model. A contingency table was constructed for the study population, comparing the screening outcome (pass or fail) to what the screening outcome would have been if performed by an eye-care provider (pass or fail), to find totals for true positive, true negative, false positive and false negative results. These values, along with the screening referral rate and estimations of the total prevalence of amblyopia in the population, could then be used to construct another table estimating screening performance characteristics for the population of children who were screened. The estimated prevalence of visual impairment in New Zealand four-year-olds used was 4.5%. The best-case scenario for screening is that all cases of unaccounted amblyopia belong to children with a positive screen but not presenting for follow-up, and worst-case that all cases of unaccounted amblyopia belong to children who passed screening. This allowed the calculation of best-and-worst case ranges for sensitivity, specific, NPV and PPV, in which the true values lie.

The relative performance of each DHB was estimated by calculating the apparent PPV for both DHBs from the absolute numbers of true positives and false positives found in the study, as this calculation is independent of any differences between disease prevalence in the two DHBs.

Totals of ocular abnormalities and the management of children who presented for further assessment were also collected, as well as a subgroup of children with severe visual impairment, defined as VA of 6/24 or worse in either eye.

Ethical approval
Ethical approval for this study was obtained from the University of Otago (Health) Research Ethics Committee. Specific informed consent for participation from the children’s parents/caregivers was not required for this retrospective audit.

Māori consultation
Specific consultation occurred with the relevant iwi (Ngāi Tahu and Ngāti Porou) through the Ngāi Tahu Research Consultation Committee and Ngāti Porou Hauora.

Results
Data collection
DHB data was obtained from three hospitals: Dunedin and Invercargill Hospitals (SDHB), and Gisborne Hospital (TDHB). There were 21 optometry practices identified in the SDHB region. Three practices in the SDHB did not have records available for retrospective identification and review, and another was unable to supply data for children seen throughout half of the data collection period. There were three optometry practices in the TDHB region, all of which supplied clinical records.

A summary of screening and referral results are shown in Table 1.

8.3% of children were referred from the B4 School Check, about half were identified as having attended a DHB eye clinic or optometry practice; follow-up information was unable to be obtained for referred children not seen.

Screening outcomes
True positive, false positive, false negative and true negative outcomes from screening for the study cohort for both SDHB, TDHB, and combined, were determined by B4SC referral status and VA measured at secondary assessment and are shown in Table 2. A child was found to have visual impairment if VA at optometry or DHB clinic was 6/9 or worse in one eye, or 6/12 or worse in both eyes—the B4SC referral criteria.

Table 3 demonstrates the screening performance measures calculated from best-case, worst-case analysis.

The potential range of sensitivity was very wide (best-case; worst-case range of 94.7%...
### Table 1: Number of children screened and outcomes of screening of the B4 School Check vision screening in the Southern and Tairawhiti DHBs in New Zealand from 1 April to 30 September 2016.

<table>
<thead>
<tr>
<th>Number of children (%)</th>
<th>Southern District Health Board</th>
<th>Tairawhiti District Health Board</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eligible for screening</td>
<td>1,942 (100)</td>
<td>402 (100)</td>
<td>2,344 (100)</td>
</tr>
<tr>
<td>Under care of eye health professional at time of screening (thus not screened)</td>
<td>54 (2.8)</td>
<td>26 (6.5)</td>
<td>80 (3.4)</td>
</tr>
<tr>
<td>Received screening</td>
<td>1,739 (92.1)</td>
<td>370 (98.4)</td>
<td>2,109 (93.1)</td>
</tr>
<tr>
<td>Referral from screening</td>
<td>134 (7.7)</td>
<td>42 (11.4)</td>
<td>176 (8.3)</td>
</tr>
<tr>
<td>Referral from screening and seen at optometrist or DHB</td>
<td>60 (44.8)</td>
<td>31 (77.1)</td>
<td>91 (51.7)</td>
</tr>
<tr>
<td>Referral from screening and not seen at optometrist nor DHB eye clinic</td>
<td>74 (55.2)</td>
<td>11 (26.2)</td>
<td>85 (48.3)</td>
</tr>
<tr>
<td>Passed screening and seen at optometrist or DHB eye clinic</td>
<td>10 (0.6)</td>
<td>15 (4.6)</td>
<td>25 (1.3)</td>
</tr>
</tbody>
</table>

### Table 2: Outcomes of testing in the B4 School Check vision screening in children subsequently presenting to an optometrist or DHB eye clinic in the Southern and Tairawhiti DHBs in New Zealand from 1 April to 30 September 2016.

<table>
<thead>
<tr>
<th>Screening outcome</th>
<th>Total (%) [SDHB, TDHB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>True positives</td>
<td>52 (44.8) [34, 18]</td>
</tr>
<tr>
<td>False positives</td>
<td>39 (33.6) [26,13]</td>
</tr>
<tr>
<td>False negatives</td>
<td>5 (4.3) [1, 4]</td>
</tr>
<tr>
<td>True negatives</td>
<td>20 (17.2) [9, 11]</td>
</tr>
<tr>
<td>Total</td>
<td>116 (100) [70, 46]</td>
</tr>
</tbody>
</table>

### Table 3: Performance characteristics of the B4 School Check for the SDHB and TDHB vision screening in the Southern and Tairawhiti DHBs in New Zealand from 1 April to 30 September 2016 in best-case and worst-case scenarios.

<table>
<thead>
<tr>
<th>Screening outcome</th>
<th>Best-case scenario</th>
<th>Worst-case scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>True positives</td>
<td>90</td>
<td>52</td>
</tr>
<tr>
<td>False positives</td>
<td>86</td>
<td>124</td>
</tr>
<tr>
<td>False negatives</td>
<td>5</td>
<td>43</td>
</tr>
<tr>
<td>True negatives</td>
<td>1,928</td>
<td>1,890</td>
</tr>
<tr>
<td>Total</td>
<td>2,109</td>
<td>2,109</td>
</tr>
<tr>
<td>Sensitivity [A/A+C]</td>
<td>94.7%</td>
<td>54.7%</td>
</tr>
<tr>
<td>Specificity [D/D+B]</td>
<td>95.7%</td>
<td>93.8%</td>
</tr>
<tr>
<td>Positive Predictive Value [A/A+B]</td>
<td>51.1%</td>
<td>29.5%</td>
</tr>
<tr>
<td>Negative Predictive Value [D/D+C]</td>
<td>99.7%</td>
<td>97.8%</td>
</tr>
</tbody>
</table>
to 54.7%), which means this study is unable to provide a meaningful estimate of vision screening sensitivity. PPV of screening was low (29.5% to 51.1%), however, the estimated range of NPV was high (97.8% to 99.7%).

**VA comparison between screening and optometry and DHB clinic assessment**

Screening VA were compared to each child’s corresponding VA from optometrist or DHB eye clinic (the ‘true’ VA), using a two-sided, paired t-test. The mean VA from screening was 6/9.80 while the mean ‘true’ VA was 6/9.27. A two-sided, paired t-test had a p value of less than 0.05, meaning there is a statistically significant (but not clinically significant) difference between VA measured by VHT from optometrists and DHB clinics.

**SDHB and TDHB vision screening comparison**

The apparent PPV for SDHB was 56.7%, whereas the apparent PPV for TDHB was 58.1%, suggesting there is likely very little difference in screening performance between the SDHB and TDHB.

**Treatment outcomes**

Any ocular abnormality and management of children who were screened and found to have truly reduced vision (less than 6/9 in one eye) by DHB clinics and optometrists was recorded and is displayed in Table 4.

**Severe visual impairment**

Of all children screened for vision in the SDHB and TDHB, and who received further assessment at a DHB eye clinic or optometry practice, there were three children (2.5%) who met the threshold for severe visual impairment (6/24 or worse in either eye). One child with severe visual impairment was seen at a DHB eye clinic and was diagnosed with anisometropic amblyopia. Two children with severe visual impairment were seen at optometry practices. One of these was diagnosed with myopia and treated with spectacles, and the other was diagnosed with anisometropic amblyopia, and referred to a DHB eye clinic for further management.

**Discussion**

This study assesses the accuracy of vision screening in two distinct regions of New Zealand and indicates that there are very few children with reduced vision who are missed by screening. However, the relatively low PPV suggests that there is a tendency to over-refer and an increased VA threshold for referral would reduce the number of false positive referrals.

The main finding of this study is a low PPV, in the range of 29.5% to 51.1%, for the vision screening component of the B4 School Check; at least half of referrals have normal vision. This is consistent with the only other study evaluating the B4SC since its inception, which found a PPV of 31% in South Auckland,14 as well as with findings from other childhood vision screening programmes around the world. Reported PPVs range from 35% to 85%, including the Rotterdam Amblyopia Screening Effectiveness Study, a seven-year follow-up study, which found a PPV of 42%.15–17 Reassuringly, there was no difference in the apparent PPV calculated from the raw outcomes between the SDHB and TDHB, suggesting that the performance of the B4SC in these two areas is comparable.

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**Table 4: Ocular abnormalities in children screened by the B4SC with visual impairment, and the management by DHB and optometry practices in SDHB and TDHB.**

<table>
<thead>
<tr>
<th>Ocular abnormality</th>
<th>Number (%) [optometry, DHB]</th>
<th>Management</th>
<th>Number (%) [optometry, DHB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive error</td>
<td>53 (93.0) [35, 18]</td>
<td>Glasses</td>
<td>47 (82.4) [32, 15]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Review later</td>
<td>6 (10.5) [3, 3]</td>
</tr>
<tr>
<td>Strabismus</td>
<td>3 (5.3) [2, 1]</td>
<td>Ophthalmology referral</td>
<td>2 (3.5) [2, 0]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Review later</td>
<td>1 (1.8) [0, 1]</td>
</tr>
<tr>
<td>Amblyopia</td>
<td>8 (14.0) [5, 3]</td>
<td>Glasses</td>
<td>7 (12.2) [4, 3]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Penalisation</td>
<td>3 (5.3) [1, 2]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ophthalmology referral</td>
<td>1 (1.8) [1, 0]</td>
</tr>
<tr>
<td>Other pathology</td>
<td>0 (0.0) [0, 0]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PPV correlates with prevalence, and amblyopia has a relatively low prevalence (1–5%). Also, the function of a screening programme is not to decide which cases do or do not have a condition, rather, it is to identify cases at risk and requiring further assessment, and a lower PPV reflects this. The implication for a relatively low PPV, however, is a significant number of unnecessary referrals are made to DHB eye clinics, as well as causing unnecessary worry and inconvenience for parents and caregivers.

The high NPV found is reassuring, suggesting children who pass vision screening are very unlikely to have a visual deficit. This is ideal for a screening programme, particularly one like the B4SC where screening is a one-off event, as it minimises the number of cases of reduced vision not detected by screening. The low PPV and high NPV may mean the B4SC criteria for referral could be raised without negatively impacting on the number of children that may be missed, which would result in fewer false positive referrals. Further study could investigate the optimal threshold for vision screening referral. Most visual deficits found in children referred from the B4SC were due to refractive error, and most of these cases were managed with a prescription of glasses. The small number of children with severe visual impairment seen by optometrists either had refractive error amenable to glasses or were appropriately referred. The implication for this is that optometrists are very well placed to be managing children referred from the B4SC and referral directly to them rather than DHB clinics would reduce reliance on DHBs for the management of these children, and this is the case in the TDHB.

This study also found VA measured at VHT screening is statistically different from VA measured at optometry and DHB eye clinics, assumed to be a child's true VA. However, it is reassuring that this difference in not clinically significant, despite inherent limitations of vision screening: suboptimal testing environments for VHTs (often in preschools with associated distractions) compared to an optometry practice; a relative lack of training for VHTs (the Vision in Pre-schoolers Group has shown that the accuracy of lay-screeners is less than that of trained eye-care professionals);18 and that a child's VA is not necessarily constant over time.19 Again, this is not necessarily inappropriate for a screening programme functioning to identify cases of reduced vision, rather than precisely quantify it.

The main issue identified by this study is the large proportion of children who failed screening and were not identified as presenting to a DHB clinic or community optometrist in the study period, particularly in the SDHB; 55% of children referred in the SDHB were unaccounted for. Explanations include children presenting beyond the data collection window, missing records from optometrists, and children not presenting at all after referral. Data collected from community optometrists was voluntary, limiting the number of practices supplying data. This potentially concerning finding, particularly if many children are indeed not presenting for further follow up after screening referral, warrants further investigation as it may be an area that can be improved. After a referral is generated by the B4SC, the parents are given responsibility for organising follow-up at an optometry practice, DHB eye clinic or private ophthalmologist. Potential barriers for parents initiating this include the perceived costs of optometry appointments and glasses prescriptions. There are optometry practices which do offer free services for children and the Children's Spectacle Subsidy does subsidise prescriptions, however, the parents' knowledge of these services is uncertain.20 DHB appointments, while free, are not equally accessible throughout New Zealand—in the SHDB, for instance, a child can be referred directly to Dunedin Hospital Ophthalmology Service from the B4SC, but not to the Invercargill Hospital Ophthalmology Service. Therefore, it is important to further investigate what is happening to children who are not found to present to an eye healthcare professional after a vision screening referral, and what barriers, if any, parents have. Another possibility for further study is to sample children in the community with gold-standard visual acuity testing and compare to screening outcomes, allowing determination of true values of sensitivity, specificity, PPV and NPV. Future vision screening research in New Zealand may also look at other aspects of screening, such as the role of photoscreeners, which are emerging in various societies as an augmentation to current screening programmes.21,22
Competing interests:
Nil.

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