
Background: Comprehensive vision screening programmes for children are an important part of public health strategy, but do not exist in many countries, including Tonga. This project set out to assess: (1) the functional vision of children attending primary schools in Tonga and (2) how a new recognition acuity test (The Auckland Optotypes displayed on a tablet computer) compares to use of a standardised eye chart in this setting.

Methods: Children from three Tongan primary schools were invited to participate. Acuity testing was conducted using a standardised recognition acuity chart (Lea symbols) and the tablet test displaying two formats of The Auckland Optotypes. Measures of ocular alignment, stereo acuity and non-cycloplegic photorefraction were also taken.

Results: Parents of 249 children consented to participate. One child was untestable. Only 2.8 per cent of testable children achieved visual acuity worse than 0.3 logMAR in the weaker eye. Results from the Spot Photoscreener suggested that no children had myopia or hyperopia, but that some children had astigmatism. The tablet test was practical in a community setting, and showed \( \pm 0.2 \) logMAR limits of agreement with the Lea symbols chart.

Conclusion: The sample of children in Tongan primary schools had good functional vision. A modified version of the tablet acuity test is a promising option for vision screening in this context.

Key words: acuity, electronic visual acuity, optotypes, Pacific, screening, Tonga
Vision screening in Tongan schools Hamm, Langridge, Black et al.

The prevalence of refractive error varies considerably between countries; 90 per cent of children in some developed parts of East Asia are myopic by the time they finish high school compared to 25 per cent globally. The prevalence of myopia is lower in primary school-aged children (approximately 40 per cent in developed parts of East Asia and 15 per cent globally). Epidemiological vision research within Tonga is scant, and has focused on adults. Knowledge about the eye health of children in the Pacific Islands is limited to a single report of school screening in Timor-Leste and some early research on refractive error in Melanesia. If Tonga is similar to these Pacific Island nations, then one would expect Tongan children to have lower rates of myopia than the global average.

Guidelines for screening tests at various ages exist, and cover chart-based and electronic recognition acuity tests through to auto-refraction and photo-screening. Newer technologies offer several advantages over traditional methods. First, many electronic tests can be run on the user's own equipment (for example the Jaeb Visual Acuity Screener can be run on any Microsoft Windows device), and can present targets (‘optotypes’) which are open-access (freely available, for example the standard Sloan letters or The Auckland Optotypes (TAO)). Second, automation of the testing procedure can reduce scoring and recording errors, streamline data storage, promote referral and facilitate follow-up.

Any system to identify children with vision impairment does not help the community unless it is supported by appropriate clinical services. In Tonga, infrastructure and human resources for eye care have been limited. In a 2005 audit of spectacle dispensing in Pacific Island countries, Tonga was the only country without a permanent public spectacle dispensing system, a gap being filled with recycled glasses. As recycled glasses can be problematic, the Fred Hollows Foundation New Zealand, Volunteer Ophthalmic Services Overseas New Zealand and other groups have assisted with provision of custom and ready-made spectacles, but no permanent local solutions are in place. At the time of the screening, the central hospital (Vaiola, serving the Tongatapu Group) had an eye clinic with three eye-care practitioners. Registered nurses trained in basic eye care supported the eye-care practitioners, of which there were two serving in the Tongatapu Group, one in the Vavau Group, and one in the Haapai Group. There was also one private optometrist in Tongatapu. The Fred Hollows Foundation New Zealand has an ongoing investment in capacity building, including developing human resources. Despite these efforts, local resources have been insufficient to serve the population, leaving Tonga reliant on several outreach teams to fill unmet needs, a common occurrence in the Pacific. Encouragingly, in the time since the project finished, Vaiola hospital has appointed an ophthalmologist.

Without estimates of the prevalence of vision problems in Tongan children, the level of required support, infrastructure and the best screening strategy remain unclear. A small-scale cross-sectional description of the visual status of schoolchildren in Tonga, therefore, serves two aims. (1) To assess vision of primary school-aged children in Tonga in terms of recognition acuity, augmented by an estimate of refractive error using a photoscreener. (2) To compare a new recognition acuity test (using open-access shapes displayed on a tablet) to use of a standardised paper chart in this setting.

Methods

Study design
To address aim one, a cross-sectional observation study, using a standard visual acuity test (crowded Lea chart) to describe functional vision, was implemented with a sample of children in Tonga. Acuity measures were accompanied by measures of non-cycloplegic photorefraction, ocular alignment and stereo acuity. To address aim two, the agreement between the Lea chart and a new electronic acuity test was measured. The new test presented TAO on a tablet computer with automated test progression, termination and scoring. The outcome measure was 95% limits of agreement (LoA) between tests from Bland–Altman plots.

This aim was augmented with an analysis of the effect of the number of trials on agreement, and by exploring whether children exhibit a bias toward some shapes over others. The assessment tools used for both aims are presented in Figure 1 (left) and described in more detail below.

Study context and setting
Visual testing was embedded within a holistic health survey in Tonga (run by author FL) that also included measurements of anthropometry, ear health, oral health and questionnaires.
The protocol for this broader study was established through the Delphi process with a diverse but primarily Tongan panel (including paediatricians, academics, teachers and parents). As part of this process, inclusion of vision testing reached 93 per cent consensus.26 A goal of the broader health survey was to promote the benefits of electronic testing, which fit well with the second aim of this project (to compare charts with electronic vision tests). Collaboration with Tongan stakeholders commenced in 2013, culminating in data collection in 2015,26 and follow-up summary reported in 2017.

Participants
The sample cohort was recruited from three primary schools in the urban capital of Tonga, Nuku’alofa. The study complied with the tenets of the Declaration of Helsinki. Ethics approval was granted by the University of Auckland Human Participants Ethics Committee and the Tonga National Health Ethics and Research Committee. Parents of 249 children provided written informed consent for their child to be included in the study. Ages ranged from five to 15 years (distribution presented in Figure 1, right), 58 per cent female. Most (85 per cent) of the children were born in Tonga, and 91 per cent spoke Tongan in their homes.

Use of standard clinical measures
The study protocol consisted of a standardised measure of visual acuity (Lea symbols27 on a paper chart), photorefraction (Welch Allyn Spot Photoscreener), ocular alignment (unilateral cover test at near), and stereo acuity (Randot preschool). Test procedures followed published guidelines.7,28 Our use of the Welch Allyn Spot Photoscreener followed guidelines given in the accompanying manual. Reporting (and referral) cut-offs for recognition acuity are diverse.2 Referall cut-offs are typically > 0.2 logMAR (logarithm of the minimum angle of resolution) or > 0.3 logMAR in either eye. By contrast, the International Classification of Diseases (ICD)-10 only classifies moderate impairment as beyond ~0.5 logMAR, and severe impairment as beyond 1.0 logMAR (http://apps.who.int/classifications/icd10/browse/2015/en#/H54).

Data here are reported at poorer than 0.3 logMAR, 0.5 logMAR and 1.0 logMAR and referrals were made for children having habitual visual acuity worse than 0.3 logMAR, to balance benefits of referrals with the limited eye-care resources available in Tonga. Standard refractive error thresholds for screening were used for reporting and referral (astigmatism > 1.50 D, hyperopia > 3.50 D, anisometropia > 1.50 D, myopia < ~1.50 D),29 as well as device-specific adjusted refractive cut-offs recently recommended (astigmatism > 1.25 D, hyperopia > 2.375 D, anisometropia > 1.125 D, myopia < −2.00 D).30

Participants needed to be able to name or match shapes in order to be classified as ‘testable’. The right eye was always tested first, followed by the left eye.

Optotypes
The electronic comparison test displayed TAO19 an open-access picture optotype set. TAO symbols were designed to be balanced in the sense that each item elicits a similar visual acuity threshold to the other items. They have been shown to produce accurate measures of recognition acuity in children in a parallel study in New Zealand.19 The researcher collecting data (author LH) was trained on Tongan names for each shape (within both TAO and Lea sets). TAO symbols were tested in regular (black stroke on white background - crowded) and vanishing (uncrowded split black and white stroke on grey background) formats. Vanishing optotypes are known to provide a more reliable measure of acuity in adults13 because they attenuate low spatial frequency information which can be used to guess the identity of a target.33

<table>
<thead>
<tr>
<th>Worse eye acuity</th>
<th>≤ 0.3 logMAR</th>
<th>&gt; 0.3 to 0.5 logMAR</th>
<th>&gt; 0.5 to 1.0 logMAR</th>
<th>&gt; 1.0 logMAR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.3 logMAR</td>
<td>241</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>241</td>
</tr>
<tr>
<td>&gt; 0.3 to 0.5 logMAR</td>
<td>5</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>&gt; 0.5 to 1.0 logMAR</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 1.0 logMAR</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>247</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>248</td>
</tr>
</tbody>
</table>

Table 1. Acuity for worse eye and better eye using standard acuity test (Lea symbols)
Analysis
The designation of the ‘weaker’ eye was based on scores from the Lea chart. If eyes had the same visual acuity, the ‘weaker’ eye was designated as the right eye. For the electronic acuity test, raw QUEST data were fit with a psychometric function to determine the threshold (smallest legible symbol size). The acuity range was set from −0.1 to 1.5 logMAR and slope from 3.3 to 50. Lapse and guess rates remained at one per cent and 10 per cent respectively. The PAL_PFL_Fit34 function was used to estimate threshold and slope from the fit of a cumulative normal distribution. Agreement between both regular and vanishing TAO tablet tests and Lea chart was evaluated in reference to the goal of 95 per cent LoA within ±0.2 logMAR, the test–retest agreement of the gold standard test for research studies in children.35

Results
Standardised screening outcomes
One child was untestable using Lea symbols. Acuity data from the remaining children are summarised in Table 1 based on the referral criteria (> 0.3 logMAR) and ICD-10 criteria (moderate > 0.5 logMAR and severe > 1.0 logMAR), and Figure 2A shows acuity results by age. No children met the ICD-10 definition for bilateral moderate or severe vision impairment, and only two met the ICD-10 criteria for moderate unilateral vision impairment. Seven children had reduced vision sufficient for referral. Three of these children showed amblyopic risk factors due to their interocular acuity difference (identified by asterisks on Figure 2A). For 33 of the 249 children, the Spot Photoscreener was unable to provide a result. None of these 33 children had worse than 0.3 logMAR visual acuity. Figure 2B summarises the refraction results by age. No children failed the screening based on suspected hyperopia or myopia regardless of criterion used; however, six children were identified with suspected astigmatism. For the seven children with acuity loss worse than 0.3 logMAR, four met the refractive criterion for astigmatism. No children had manifest near strabismus based on the unilateral cover test or the Spot Photoscreener result.

Eighty per cent of children could see the stereo acuity targets equal to or better than 60 seconds of arc disparity. Twelve children could not see disparity cues of 800 seconds of arc. One of these children had bilateral recognition acuity impairment, and two had mild unilateral impairment and astigmatism.

Figure 2. Outcome measures by age and eye. A: Acuity thresholds using the Lea symbols wall chart. The x-axis represents age and the y-axis visual acuity in logMAR. Shaded regions highlight ±0.2 and ±0.3 logMAR. B: Measures of refractive error from the Spot Photoscreener, whereby the x-axis is age, and the y-axis is refraction in dioptres. No children failed according to myopia or hyperopia American Association for Pediatric Ophthalmology and Strabismus (AAPOS) criteria28 or adjusted AAPOS according to Mu et al.;29 however, six failed for astigmatism (one only according to the adjusted criterion). Participants meeting fail criteria for refraction, acuity or both are highlighted in each panel, and summarised in the legend.
To understand the impact of the number of trials, the LoA was recalculated based on the results from a truncated staircase. Each data point in Figure 4A represents theoretic LoA with Lea (the example for 10 trials is shown in the insets). From the calculated knee point of the exponential fit (solid line), it appears that after seven trials, additional trials yield diminishing returns (in terms of agreement with the Lea chart).

If each optotype was matched to the rest of the shapes within a set (in terms of both legibility and child preference) one could expect a 0.1 probability of correct response for each shape. For the regular format of the optotypes, the probability of correctly reporting a shape ranged from 0.07 to 0.14. The vanishing formats of the optotypes elicited a narrower range of probabilities. This suggests that the children found some of the regular variants easier (in this case □ and △), rather than having a bias toward answering some shapes over others (such a preference would likely impact both formats). However, if only data from younger children (5–6 years) are evaluated, the range increases, and the correlation between regular and vanishing formats becomes significant. This suggests younger children showed a preference toward certain shapes over others. In particular, the □ and △ were reported more frequently in these younger children (Figure 4B).

Follow-up
The clinical team reviewed all cases. Referrals were based primarily on defined Lea acuity and photoscreener cut-offs. Stereoscopic acuity and ocular alignment results were reviewed in participants with borderline acuity and/or refractive findings. Nine children were referred to the local eye clinic, each from a different family. One was untestable, two had suspected astigmatism but acceptable acuity, four had reduced visual acuity and suspected astigmatism, and one had visual acuity loss but non-cycloplegic photoscreener results below the referral criteria. Two children had reduced acuity on the Lea symbols chart, but normal TAO acuity and photo-screener results. We referred the participant for whom the mean acuity result was worse than 0.3 logMAR (yellow) and stereo acuity was unmeasurable, but not the child for whom mean acuity was better than 0.3 logMAR and stereo acuity was 40 seconds of arc (pink).

As part of the larger study, a referral process was instigated through Vaiola Hospital to facilitate better flow of children needing care to the appropriate facilities. For the vision screening component presented here, one family informed the researchers that they organised spectacle correction for their child independently, two families followed up with the eye clinic in Nuku’alofa, and the remaining six families did not attend the local health clinic for follow-up. The families who attended the local clinic were encouraged to return when a visiting team of volunteers arrived, but neither did. Note that the local ophthalmologist was appointed after completion of the study. For the families who did not attend the local clinic, some may have arranged care independently, some may have decided not to follow-up and others may have been unable to.

Although the referral process was an improvement on the first-come first-served system, more active follow-up would be required in order to better understand long-term outcomes, and barriers to accessing eye care.

Discussion

Lea chart acuity and photoscreener outcomes
Most children who participated in the study had normal functional vision according to the Lea test. No children met the ICD-10 definition for bilateral vision impairment, and only three met the criteria for having an amblyogenic risk factor. Only 2.8 per cent of children had habitual vision worse than 0.3 logMAR in their weaker eye, most due to suspected astigmatism. No children failed the screening due to suspected hyperopia or myopia.

Comparison of these results to epidemiological work is challenging given: (1) the small sample; (2) the use of the non-cycloplegic Spot Photoscreener as an estimate of refraction; and (3) the difference between cut-offs used in epidemiological work 25 compared to that used for clinical referral. 28 With these caveats in mind, the refraction data suggest that Tongan school children experience lower levels of myopia than children from developed parts of South East Asia, 8 with our results being more in line with the rates of myopia reported in other Pacific Islands. 14–16 Increased time outdoors and decreased emphasis on education have been associated with decreased prevalence of myopia. 8 Increased outdoor time was recently found to be preventative
in a clinical trial in China, and there has been some advocacy encouraging children to go outside to counteract myopia. In the current project, each participating school had natural light in classrooms, excellent outdoor spaces and promoted a culture of outdoor activity. Although these observations fit with the literature, the small cross-sectional study presented here cannot speak to causality.

While the data suggested low rates of myopia, there appeared to be higher levels of mild astigmatism compared to international norms. It has been reported that astigmatism is associated with keratoconus, and that Pacific students in New Zealand high schools have higher rates of keratoconus than their European peers. Again, although these findings may be related, the present study design precludes comment on whether the higher prevalence of mild astigmatism seen in this sample of Tongan children is associated with a higher incidence of keratoconus later in life.

**Efficacy of new recognition acuity test**

The agreement between the Lea chart and the TAO tablet tests are similar to test–retest reliability for the research standard for children, and this level of agreement could be achieved in fewer than 10 trials. As is the case for all agreement metrics with a subjective gold standard, inaccurate Lea test results would manifest as poor agreement. Figures 2 and 3 suggest this may have occurred in the present study; the participants represented by yellow and pink achieved excellent results on both TAO tests, but poor Lea results. Such a large gap between acuity results is more likely due to lapses on the test with the poor result (due to inattention or disengagement) than lucky guesses on the tests with the better result (particularly for an optotype set with 10 alternatives). Although these children did not have full eye examinations, the Spot Photoscreener reported emmetropia, again suggesting the TAO results better reflected true acuity thresholds. It is possible that visual acuity at 1.5 metres could impede the detection of low myopia up to approximately −0.75 D. However, this did not appear to be the case; among participants with ≤−0.75 D spherical equivalent in the worse eye, an equal number of participants performed poorer on the Lea chart (three metres) and TAO regular and vanishing optotype tablet test (1.5 metres).

Although agreement with the Lea chart was acceptable, this project provided the opportunity to consider modifications to improve acuity threshold estimation. For example, some children answered incorrectly on the first trial of a TAO staircase despite correctly identifying subsequent, smaller symbols. Some of these early lapses prevented the short staircase from converging, resulting in unreliable threshold estimation. Implementation of a formal assessment of testability, as a short pre-test, could reduce early lapses. Similarly, increasing the staircase procedure’s initial guess for threshold (the ‘prior’) would likely limit the impact of early lapses. Incorporating a ‘refresh’ option to show a child a second presentation at the same stimulus level could also reduce the instance of such lapses. Indeed, in a parallel study in New Zealand, these modifications were implemented in the tablet tests and resulted in agreement as good as ±0.14 logMAR.

The tablet allowed automated selection of stimulus level, termination criteria, and both scoring and recording of results, a practical advantage that freed the examiner to engage with the child. If the testing device could be integrated with the health-care system, automation could also help with
referral and follow-up. Given their advantages, electronic acuity tests are being used more in community settings, and are increasingly recommended for a variety of applications including visual acuity measurements and screening. Disadvantages of such devices include the need for electricity and for specific testing environments to appropriately position the tablet, and reduce glare on the screen.

The optotypes used (TAO) were easily identifiable by the children, confirming appropriateness of TAO for this age and culture. However, there was a trend in younger children (5–6 years old) toward choosing particular shapes (G and O) for their answer. An assessment of bias in preschool children could establish whether such preferences are exaggerated in even younger children.

The agreement of regular and vanishing optotypes with Lea symbols was identical. However, the analysis of trial number theoretically allow the same agreement. Even if they had been, recycled glasses may compromise quality and compliance, and increase reliance on external sources of support. Ready-made glasses have been proposed as a cost-effective alternative.

Low rates of vision impairment perhaps raise the question of how much infrastructure ought to be devoted to large-scale vision screening. However, it is possible that our sample was not representative. Although most children in Tonga are enrolled in primary school, it is possible that our sample was not representative. Although most children in Tonga are enrolled in primary school, it is possible that our sample was not representative.

**Considerations for population-wide childhood screening**

The relative benefits and risks of population-wide preschool vision screening have been reviewed, and screening recommended. However, the benefits that vision screening imparts are dependent on early detection of vision disorders leading to early treatment. In Tonga, there is not yet an adequate system for referral or provision of glasses.

Additional infrastructure would be required for appropriate referral, treatment and follow-up before a vision screening programme would benefit the community. A recent study investigated the qualitative impact of providing free glasses at school. The authors report that providing the glasses in school (as opposed to clinics) increases access to, and use of, spectacles, and that use of glasses improved performance in school and psychosocial wellbeing. School-based provision of health care in general is a promising strategy, and pairing vision screening with other health domains could reduce human resources required for testing, referrals and follow-up.

A sustainable system for providing and funding glasses is also required. Recycled glasses are not ideal; appropriate recycled glasses were not available for any of the vision problems detected as part of the recent study. Even if they had been, recycled glasses may compromise quality and compliance, and increase reliance on external sources of support. Ready-made glasses have been proposed as a cost-effective alternative.

**Conclusion**

The children tested in Tonga had good vision, with mild to moderate loss mostly attributable to suspected astigmatism. The electronic recognition acuity task using TAO in the regular format was practical for testing in community environments and showed acceptable agreement with a standardised chart, with potential for further improvements to optimise screening. However, it is of note that the infrastructure in Tonga would need to be expanded for population-wide screening to be beneficial.

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**REFERENCES**


