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Visual profiling and vision screening of preschool children in Greenland

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ABSTRACT

A population-based cross-sectional study was conducted in six towns in Greenland to establish normative data on refraction and visual acuity in preschool children and to develop a practical vision screening method suited to Greenlandic healthcare needs. We recruited 274 children born in 2017 through kindergartens in six towns. The only exclusion criterion was known eye disease under ophthalmological care. Vision screening was performed by an optometrist, assessing distance visual acuity with Kay Pictures, binocular near visual acuity with Lea Symbols, stereoacuity with the Lang II Test, and non-cycloplegic refraction using the Plusoptix A12R. An ophthalmologist conducted follow-up examinations, including cycloplegic refraction, within one week. Of 532 eligible children, 274 participated (144 boys, 133 girls; mean age 4.7 years). The mean visual acuity for the worse- and best-seeing eye was 0.05 (±0.16 SD) and 0.01 (±0.12 SD) logMAR, respectively. Cycloplegic myopia (≤-0.5 dioptres) was found in 5%, while 18% had hyperopia >+2.0 dioptres. Most preschool children in Greenland have good visual acuity and mild hyperopia. Vision screening combining the Plusoptix autorefractor and distance visual acuity demonstrated the highest sensitivity (89%) for identifying children needing further evaluation. Implementing this vision screening method in kindergartens is recommended to improve early detection and treatment outcomes.

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Introduction

Greenland's healthcare system suggests conducting the first vision screening of preschool children at the age of four as part of routine health examinations in accordance with global recommendations [1,2]. The primary objective of vision screening is to detect amblyopia and other eye conditions when treatment is most effective, thereby preventing long-term or permanent visual impairment [3–5]. The current vision screening procedure in Greenland measures only distance visual acuity.

Greenland is the world's largest island with a predominantly Inuit population, where specialised healthcare services, including ophthalmology, face significant challenges. With a population of approximately 56,000 people and an annual birth rate of approximately 800 children [6], the healthcare system is divided into five regions, each with a regional hospital providing primary healthcare. The Capital region houses the National Hospital, which offers specialised care for the entire country. However, there is a high turnover of healthcare professionals, especially outside the capital, Nuuk, which challenges the healthcare system.

Ophthalmological patients are examined via telemedicine in nine towns, with tests such as visual acuity measurements and fundus photography, which are sent to ophthalmologists in Denmark for assessment. Each town is also visited annually by a consulting ophthalmologist for one to two weeks. Despite these efforts, there is no permanent ophthalmologist in Greenland, and specialised eye care is limited. Greenland has 11 local optometrists, who travel annually to towns and settlements. However, these optometrists do not routinely examine children as part of their daily practice, highlighting a significant gap in accessible eye care.

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This limitation in eye care access is not unique to Greenland but also affects other regions within the circumpolar area [7–9].

The use of instrument-based vision screening, such as photoscreeners, in addition to visual acuity testing in children, appears to increase the sensitivity of vision screening and makes vision screening more accessible [10–12].

The effectiveness and participation rates of Greenland's current vision screening programme remain unclear. However, Duelund et al. [13], found in a recent study that 5% of 6-year-old children in Greenland did not have the appropriate eyeglass prescription, suggesting that vision anomalies in children are significantly underdiagnosed in Greenland.

The aim of this study was to establish normative data on refraction and visual acuity for preschool children with no prior contact with eye care professionals in Greenland and to develop a new, practical vision screening method tailored to the special challenges and needs of Greenlandic healthcare settings, including a comparison of the accuracy between the screening method and a detailed ophthalmic check-up.

Methods

Design

The study was designed as a population-based cross-sectional study conducted in three towns with local optometrists and three towns without access to optometrists in four of the five regions in Greenland (Figure 1). The towns were chosen based on their size, as they were large enough to accommodate a sufficient number of children for examination at a relatively low cost. This selection also ensured that the study could be conducted within the logistical constraints of Greenland's vast geography.

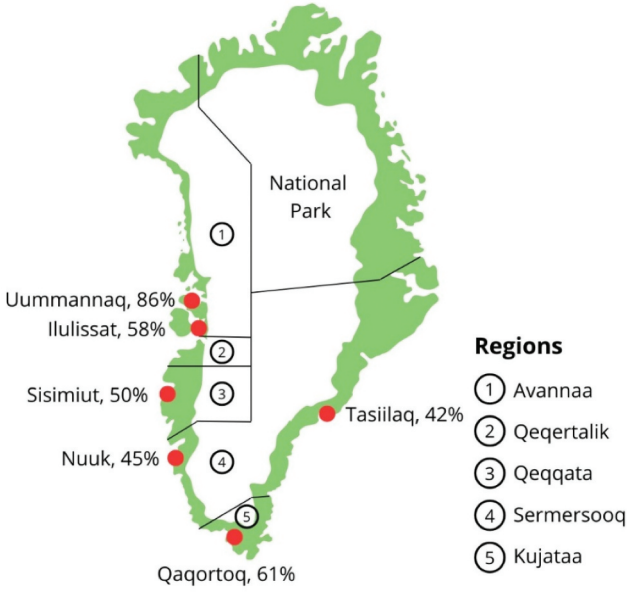

Figure 1. Map of Greenland highlighting the regions and towns visited for this study, labelled with the participation rates in each location, expressed as percentages of the 5-year-old children as of January 1, 2023.

Study population

Children born in 2017 attending kindergarten in the six towns were invited to participate (Figure 2). The number of kindergartens in these towns ranged from 2 to 18, with a median of 5 and a mean of 7. Written information for parents about the project was sent to the kindergartens one week prior to the vision screening. Oral information was also provided by the ophthalmologist (ND) before written consent was obtained from the parents. Children with known eye disease already under the care of an ophthalmologist were excluded from the study, as the aim was to establish normative data for healthy children. This exclusion ensured that the study's results would reflect a baseline for the general preschool population, as the vision screening programme is intended for children with no prior contact with eye care professionals. All participants were offered both a vision screening and an eye examination.

Data collection took place between November 2021 and February 2023, with a pause between December 2021 and February 2022 due to the COVID-19 pandemic. This study followed the Declaration of Helsinki and was approved by the Greenland Science Ethics Committee (ID-number 2023–15841), the Greenlandic Health Service, and the Municipalities in the participating regions.

Vision screening and ophthalmological examination

The screening was conducted by an optometrist at the child's kindergarten. The optometrist was either a local (MON, ION, IOI, SN, NSS) or one travelling from Nuuk (MON, ION). All participating optometrists received specific oral instructions on the screening procedures prior to the screening.

The screening assessed binocular and monocular distance visual acuity using uncrowded multiple-line Kay Pictures at 3 metres (Kay Pictures LTD, Hertfordshire, UK) and binocular near visual acuity with uncrowded multiple-line Lea Symbols at 40 cm (Lea Test Intl, LLC, Etters, PA, USA). A point pad was

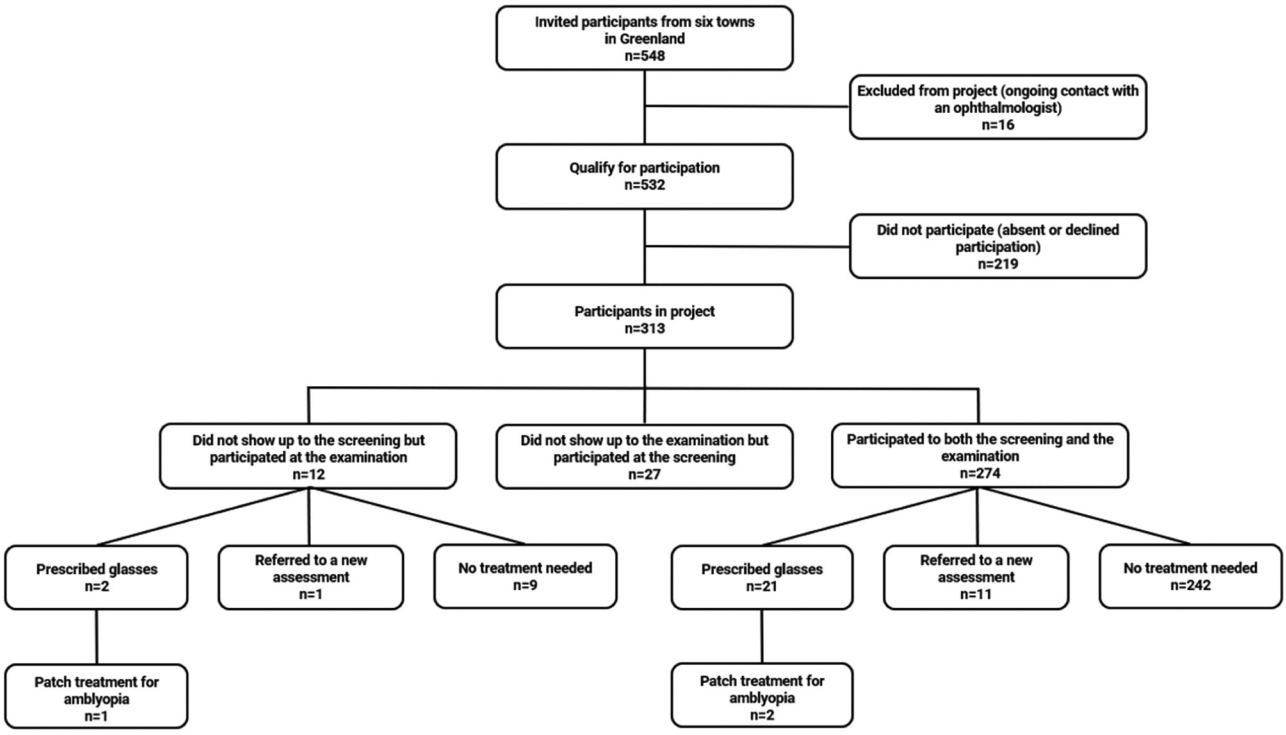

Figure 2. Flowchart showing participants in this study.

provided for both tests if necessary. Stereoacuity was measured with a Lang II Test (Lang-Stereotest AG, Küsnacht, Switzerland) at 40 cm, and non-cycloplegic refraction was measured using the Plusoptix A12R from a distance of 1 metre in a dimly lit location (Plusoptix GmbH, Nuremberg, Germany). The Plusoptix uses infrared technology to calculate refraction, similar to retinoscopy using the transillumination test [14]. The Lea Symbols chart was used instead of Kay Pictures for near VA due to supply issues caused by the COVID-19 pandemic.

The subsequent eye examination was conducted at the local hospital one to seven days after the vision screening. The same ophthalmologist (principal investigator, ND) examined all children. The examination mirrored the screening assessments and included additional tests for strabismus, slit lamp examination, ophthalmoscopy with cycloplegia (indirect using headlamp and 28 dioptres (D) lens), and autorefraction with cycloplegia (30 minutes after two drops of 1% Cyclopentolate) using a handheld Nidek HandyRef-K autorefractor (Nidek Co. Ltd., Gamagori, Japan). This comprehensive ophthalmic check-up is considered the gold standard for evaluating the accuracy of the vision screening results. At the eye examination, the child was assessed as either healthy, needing glasses, or requiring further evaluation by a routine consulting ophthalmologist from Denmark within one year. The prescription of glasses followed guidelines established by the American Association for Pediatric Ophthalmology and Strabismus (AAPOS) [15], although the final decision to prescribe glasses was always individualised. For both the screening and the ophthalmological examination, the same charts and testing distances were used. However, we could not control the exact illumination level; the lights were as bright as the location allowed, and curtains were used to avoid direct sunlight on test charts.

Visual acuity results were evaluated for the worse-seeing eye, better-seeing eye, refraction for the most hyperopic eye, least hyperopic eye, most astigmatic eye, least astigmatic eye, and the spherical equivalent (SE) refraction for both eyes.

Amblyopia was defined as a VA of ≥0.3 logMAR, in accordance with previous studies from Greenland [13] and Denmark [16].

Significant refractive errors were defined as following: hyperopia (>2.0 D), myopia (≤−0.5 D), astigmatism (≤−1.0 D) accordance with previous studies from Greenland [13] and Scandinavia [16–18].

Statistical analysis

Normally distributed continuous data were summarised as mean and standard deviation (SD), whereas median and interquartile range (IQR) were reported for non-

normal data. Normally distributed differences between the screening and the ophthalmological examination were examined with paired t-tests, while categorical data were analysed with the Stuart-Maxwell test.

Receiver Operating Characteristics (ROC) and Area Under the Curve (AUC) were calculated for all continuous data. These calculations were used to determine the cut-offs with the highest sensitivity for significant refractive errors measured by the Plusoptix autorefractor (Figure 5b). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated to evaluate the efficacy of the vision screening methods for determining the need for referral to an ophthalmological examination.

The participation rate was calculated using data from Statistics Greenland [6].

Data analysis was conducted using statistical analysis software R (version 4.2.3).

Results

The number of children qualified to participate in this project, excluding 16, was 532 in the six participating towns, of which 313 accepted the invitation. No information about the non-participants could be obtained. A total of 274 children (144 boys and 133 girls) who participated in both the screening and the ophthalmological examination were included (Figure 2).

The mean age of participants at the screening was 4.7 years (range: 4.1 to 6.1 years, standard deviation [SD]: 0.40).

The distance visual acuity (VA) measurements during the screening were 0.02 (SD ±0.15) logMAR for the worst-seeing eye and −0.02 (SD ±0.11) for the best-seeing eye, measurements for near VA averaged 0.11 (SD ±0.14). At the ophthalmological examination, monocular distance and near VA measurements were significantly worse than those obtained at the screening. However, this difference was not clinically significant (<one line difference). Additionally, children had difficulty maintaining the 40 cm test distance for near VA measurement.

The non-cycloplegic refractions obtained from the Plusoptix during the screening showed a lower magnitude of hyperopia (mean: +1.05 D SE (SD ±0.69) of all above 0 D) and a higher magnitude of myopia (mean: −0.70 D SE (SD ±0.86) of all below 0 D) compared to the cycloplegic refractions measured during the ophthalmological examination (mean: +1.57 D SE (SD ±1.20) for hyperopia and −0.63 D SE (SD ±0.55) for myopia). Using the Plusoptix, non-cycloplegic refractions were as follows: 13% of the children had hyperopia (>2.0 D), 3% had myopia (≤−0.5 D), 19% had astigmatism (≤−1.0 D), and as spherical equivalents, 22% had hyperopia, and 3% had myopia. The corresponding cycloplegic refractions were 22% for hyperopia, 5% for myopia, 15% for astigmatism, and for the spherical equivalent, 18% had hyperopia and 6% had myopia.

The axes of the astigmatism measured by the Plusoptix were equally distributed among with-the-rule, against-the-rule, and oblique [19] (χ^2-test, $p = 0.14$), while the with-the-rule was the most common axis in the cycloplegic measurements (χ^2-test, $p < 0.001$).

Most children exhibited a stereoacuity of 200 seconds of arc at both the screening and the ophthalmological examination. However, a significantly greater number of children showed improved stereoacuity scores at the ophthalmological examination (Stuart-Maxwell test, $p = 0.01$), as detailed in Table 1.

At screening, the distance VA for the worse-seeing eye was the single measure that showed the highest sensitivity for the need for referral to an ophthalmologist (= failed the screening) and combining this measure with Plusoptix further increased sensitivity while specificity was reduced. Adding additional measurements continued to enhance sensitivity but further compromised specificity (Table 2).

The VA measurements of the worse-seeing eye from the screening and the ophthalmological examination showed a mean difference of −0.02 logMAR [95% CI: −0.25, 0.20], as illustrated in Figure 3a.

The Bland-Altman plots (Figure 3b) for spherical equivalent refraction measurements showed that non-cycloplegic refractions tend to underestimate refraction by approximately 0.38 D for the right eye [95% CI: −2.44 to + 1.69] and 0.40 D [95% CI: −2.51 to + 1.72] for the left eye.

The Receiver Operating Characteristic (ROC) curves demonstrated that the visual acuity of the worse-seeing eye exhibited excellent discrimination (AUC >0.8). The interocular difference in distance visual acuity and Plusoptix autorefraction for hyperopia, myopia, and astigmatism showed acceptable discrimination (AUC 0.7 to 0.8). In contrast, near visual acuity, Plusoptix autorefraction for anisometropia, and the Lang stereoacuity test displayed below acceptable discrimination (AUC <0.7) (Figures 5a,b). Utilising these ROC curves, optimal cut-offs were established for the Plusoptix to achieve the best sensitivity and specificity, which were: hyperopia > +2.00 D, myopia ≤ −0.5 D, astigmatism ≤ −1.00 D, and anisometropia ≥ 1.00 D (Supplementary 5). The ROC curves also provided the optimal cut-off for the VA measures, which was ≥ 0.2 logMAR or an interocular difference of two or more lines.

Table 1. Data from the screening versus ophthalmological examination.

Measurement	Screening	Examination	Mean Difference	95% Confidence Interval	p-value
Visual acuity logMAR					
Binocular (3 m)	−0.04 ± 0.10	−0.03 ± 0.11	−0.01	−0.01, +0.01	0.48[1]
Worst-seeing eye (3 m)	0.02 ± 0.15	0.05 ± 0.16	−0.03	−0.04, −0.01	<0.001[1]
Best-seeing eye (3 m)	−0.02 ± 0.11	0.01 ± 0.12	−0.03	−0.04, −0.02	<0.001[1]
Binocular near (0.4 m)	0.11 ± 0.14	0.13 ± 0.09	−0.02	−0.03, −0.001	0.04[1]
Refraction in dioptres					
Least hyperopic eye	+0.92 ± 0.84‡	+1.28 ± 1.24*	−0.35	−0.51, −0.20	<0.001[1]
Most hyperopic eye	+1.25 ± 0.90‡	+1.65 ± 1.35*	−0.38	−0.54, −0.24	<0.001[1]
Myopia: −1.75 to −0.50 ($n = 13$)¥	−0.23 ± 1.16	−0.73 ± 0.46	+0.50	−0.21, +1.21	0.15[1]
Emmetropia and mild hyperopia: −0.25 to + 2.00 ($n = 184$)¥	+1.00 ± 0.68	+1.10 ± 0.55	−0.09	−0.22, 0.03	0.15[1]
Hyperopia: +2.00 to + 7.25 ($n = 49$)¥	+1.51 ± 1.17	+3.34 ± 1.30	−1.66	−1.97, −1.34	<0.001[1]
Spherical Equivalent Right Eye	+0.78 ± 0.75‡	+1.20 ± 1.22*	−0.38	−0.51, −0.24	<0.001[1]
Spherical Equivalent Left Eye	+0.83 ± 0.81‡	+1.28 ± 1.25*	−0.40	−0.54, −0.26	<0.001[1]
Least astigmatic eye	−0.25 (−0.50, −0.25)‡	−0.25 (−0.50, −0.25)*	−0.02	−0.06, +0.02	0.36[1]
Most astigmatic eye	−0.50 (−0.75, −0.25)‡	−0.50 (−0.75, −0.25)*	−0.06	−0.10, −0.01	0.02[1]
Categorised†:					0.10[2]
With-the-rule: 0–15°, 165–179°	n = 24‡	n = 31*			
Against-the-rule: 75–105°	n = 15‡	n = 3*			
Oblique: 16–74°, 106–164°	n = 13‡	n = 6*			
Lang II Test (seconds of arc)	200 (200, 200)	200 (200, 200)			0.01[2]
200 arcsec	n = 215	n = 236			
400 arcsec	n = 25	n = 17			
600 arcsec	n = 2	n = 3			
>600 arcsec	n = 23	n = 12			

Mean ±sd or Median (IQR 0.25, 0.75).
1: Paired t-test of mean differences.
2: Stuart-Maxwell Test.
‡: Non-cycloplegic refractions.
*: Cycloplegic refractions.
¥: Measurements from the right eye. The cycloplegic measurements are used as the reference.
†: Including only ≤-1D from the most astigmatic eye.

Table 2. Efficacy of paediatric vision screening methods for referral based on need for ophthalmological evaluation.

	Sensitivity	Specificity	PPV	NPV
One measurement				
Distance VA*	0.72 (23/32)	0.91 (220/242)	0.51 (23/45)	0.96 (220/229)
Near VA ≥ 0.2 binocular (logMAR)	0.47 (15/32)	0.77 (187/242)	0.21 (15/70)	0.92 (187/204)
Abnormal Plusoptix‡	0.53 (17/32)	0.78 (189/242)	0.24 (17/70)	0.93 (189/204)
Lang II Test > 400 arcsec	0.28 (9/32)	0.93 (226/242)	0.36 (9/25)	0.91 (226/249)
At least one abnormal result of two measurement				
Distance VA* **OR** Near VA ≥ 0.2 binocular	0.81 (26/32)	0.72 (175/242)	0.28 (26/93)	0.97 (175/181)
Distance VA* **OR** Abnormal Plusoptix‡	0.89 (28/32)	0.70 (171/242)	0.29 (28/99)	0.98 (171/175)
Distance VA* **OR** Lang II Test > 400 arcsec	0.72 (23/32)	0.88 (213/242)	0.44 (23/52)	0.96 (213/222)
At least one abnormal result of three measurement				
Distance VA* **OR** Near VA ≥ 0.2 binocular **OR** Abnormal Plusoptix‡	0.94 (30/32)	0.55 (134/242)	0.22 (30/138)	0.99 (134/136)
Distance VA* **OR** Near VA ≥ 0.2 binocular **OR** Lang II Test > 400 arcsec	0.84 (27/32)	0.68 (164/242)	0.26 (27/105)	0.97 (164/169)
Distance VA* **OR** Lang II Test > 400 arcsec **OR** Abnormal Plusoptix‡	0.88 (28/32)	0.66 (159/242)	0.25 (28/111)	0.98 (159/163)
At least one abnormal result of four measurement				
Distance VA* **OR** Near VA ≥ 0.2 binocular **OR** Lang II Test > 400 arcsec **OR** Abnormal Plusoptix‡	0.94 (30/32)	0.55 (125/242)	0.20 (30/147)	0.98 (125/127)

VA = Visual Acuity (logMAR).
*Distance VA = Monocular Distance VA ≥ 0.2 worse eye (logMAR) OR ≥ 2-line difference in VA.
‡Hyperopia >+2.00 D, myopia ≤-0.5 D, astigmatism ≤-1.00 D or anisometropia ≥ 1.00 D.
Threshold: Visual Acuity of 0.2 logMAR and abnormal Plusoptix‡.

At the screening, a slightly lower proportion of children had visual acuity of 0.2 logMAR or worse than at the ophthalmological examination (15% vs 18%, χ^2-test, $p = 0.48$) (Figure 4).

Exophoria was found in 33 children during the ophthalmological examination, while three children had esophoria, and one child had esotropia. The slit lamp examinations revealed one child had iris coloboma, and ten children had persistent pupillary membranes as a single string. Nine children had insufficient convergence (≥10 cm from the nose).

Based on VA measurements at the screening, 10 of the 32 children who required an ophthalmological examination had a VA of <0.2 logMAR (seven were

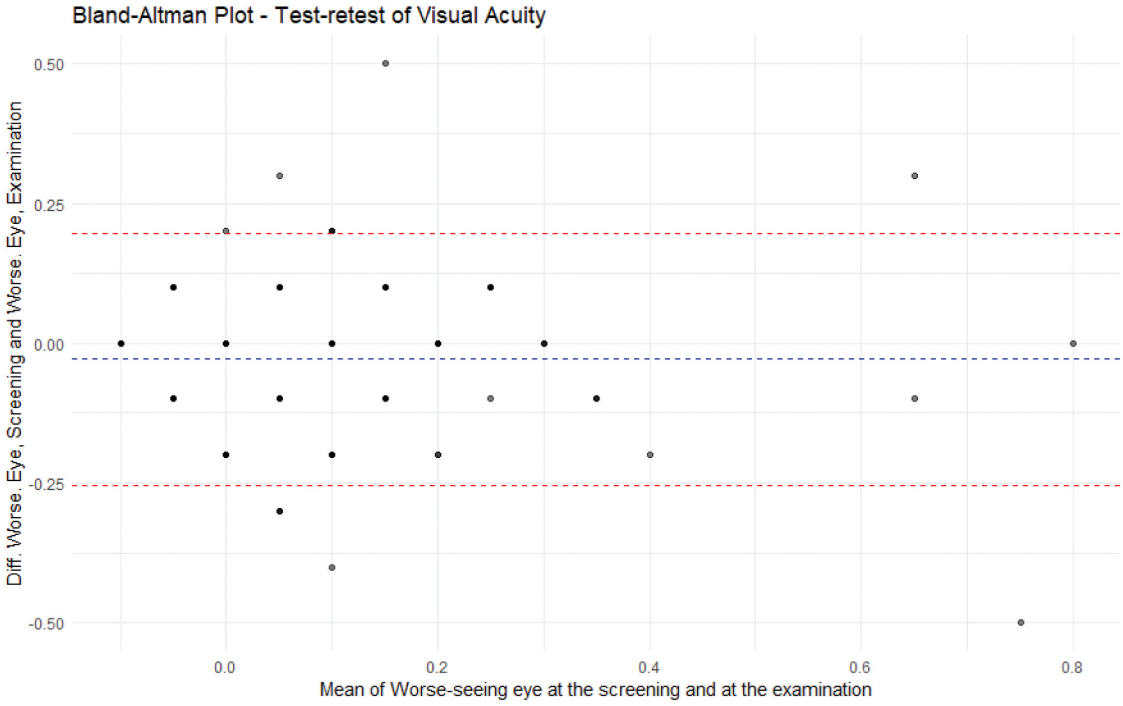

Figure 3a. This Bland-Altman plot assesses the agreement between visual acuity measurements of the worse-seeing eye during screening and subsequent examination. The plot displays the differences between the two measurements against their mean. The blue dashed line represents the mean difference (-0.03 logMAR), while the red dashed lines indicate the 95% limits of agreement, extending from -0.25 to 0.20 logMAR. The spread of points reflects the variability in measurement agreement across the sample, highlighting both consistency and instances of discrepancy between test-retest measures.

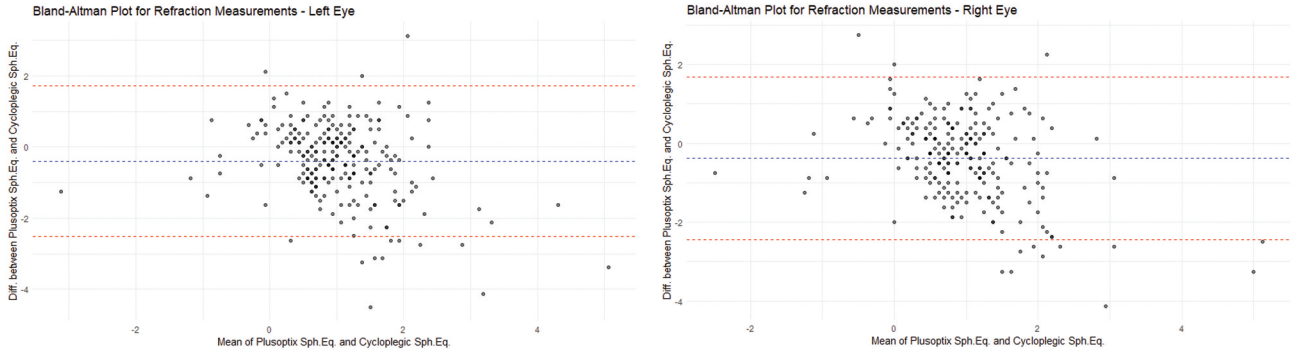

Figure 3b. These Bland-Altman plots compare non-cycloplegic and cycloplegic spherical equivalent (Sph.Eq.) refraction measurements for both the right and left eyes. Each plot shows the difference between Plusoptix and cycloplegic measurements plotted against their average. **Right Eye (Right plot)**: The mean difference is -0.38 dioptres, with 95% limits of agreement ranging from -2.44 to +1.69 dioptres, indicating variability in measurement agreement. **Left Eye (Left plot)**: The mean difference is -0.40 dioptres, with 95% limits of agreement extending from -2.51 to +1.72 dioptres, similarly highlighting measurement variability. Blue dashed lines represent the mean differences, while red dashed lines mark the 95% limits of agreement. The plots illustrate the tendency of non-cycloplegic measurements to underestimate refraction compared to cycloplegic assessments in both eyes.

prescribed glasses, and three were not prescribed glasses but required further evaluation). Of these ten children, five had an abnormal Plusoptix measurement. A total of 40 children had a VA of ≥0.2 logMAR in the worse-seeing eye at the screening. Twenty of these children were referred to an ophthalmologist, while the other 20 were not. Among the 20 children who were not referred, a subsequent VA measurement showed that only six still had a VA of 0.2 logMAR or better (range of all 20 children: −0.1 to 0.2 logMAR) and did not need glasses, as their cycloplegic refraction was normal

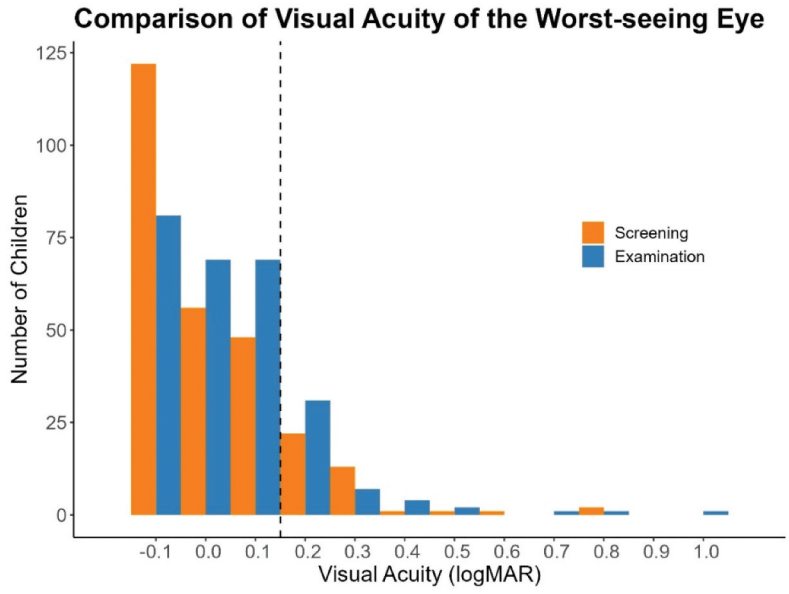

Figure 4. Visual acuity (VA) measurements of the worst-seeing eyes measured at the screening (orange) and at the ophthalmological examination (blue). The dashed line marks a VA of 0.2 logMAR or above to illustrate the number of visually impaired children in Greenland.

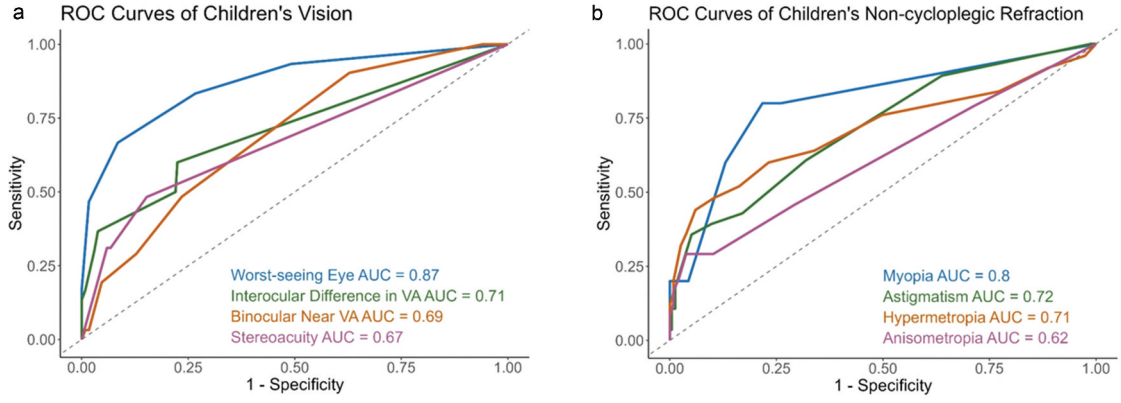

Figure 5. a and b: Receiver Operating Characteristic (ROC) curves and Area Under the Curve (AUC) values for visual acuity and non-cycloplegic refraction from the screening, respectively. These plots assess the diagnostic effectiveness of each measure in determining the necessity for referral. AUC values greater than 0.8 indicate excellent discrimination, values between 0.7 and 0.8 suggest acceptable discrimination, and values below 0.7 indicate poor discrimination. Cutoffs for referral based on refraction are hyperopia ≥0 dioptres (d), myopia ≤0 D, astigmatism ≤0 D, and Anisometropia ≥0 D.

VA = Visual acuity

for their age group. All measurements are provided in had a VA of 0.2 logMAR or better (range of all 20 children: −0.1 to 0.2 logMAR) and did not need glasses, as their cycloplegic refraction was normal for their age group. All measurements are provided in Supplementary 2.

A comparison between the children who participated fully in this study and those who only attended the screening, or the ophthalmological examination revealed that the non-participants were 2 months younger and had a VA of the right eye that was 0.15 logMAR worse at the ophthalmological examination ($p = 0.01$ and $p = 0.04$, respectively). All other measurements showed no significant differences. (Supplementary 3).

The estimated cost of the screening method, incorporating distance visual acuity and the Plusoptix, is projected at 395 DKK per child in the first year,

decreasing to 79 DKK in the second year due to initial one-time expenses. A cost analysis for the new vision screening can be seen in Supplementary S4.

Discussion

The present study presents the first set of normative data on visual acuity and refraction in Greenlandic preschool children with no previous contact with an ophthalmologist and assesses the efficacy of the vision screening. The study included 33% of all children born in Greenland in 2017 [6], suggesting that the findings represent preschool children in this region. However, the lack of data from children who declined to participate and the 10% who did not consent to cycloplegic refraction introduce a risk of bias but do not necessarily influence the screening efficacy, hence of minor importance. While these factors may affect the results, the broad geographic coverage and adequate participation rate in the present study suggest that the results can be generalised to preschool children in Greenland. However, children with esotropia and amblyopia were most likely already being treated and thereby excluded from this study, hence these prevalence's might be underestimated. The main reason parents declined participation was that the ophthalmological examination took 1–1.5 hours to complete and required the use of eye drops.

Distance VA was assessed using Kay Pictures to reduce completion failure while maintaining good test-retest variability [20–22]. Although Kay Pictures may yield slightly better VA results compared to Early Treatment Diabetic Retinopathy Study (ETDRS) [20], this difference has minimal clinical significance in children with normal vision, as expected in a screening setting. Additionally, children often struggle to complete an examination using the ETDRS chart [21], while Kay Pictures have shown high testability in children aged four years [23]. Distance VA was assessed with Kay Pictures to reduce completion failure while maintaining good test-retest variability [20–22]. The Plusoptix was used as previous studies have shown that this device is useful for identifying preschool children with significant refractive errors in a vision screening setting [10,24,25]. The Lang II Test was included to evaluate whether it could enhance the sensitivity of the vision screening method. It provides a simple way to assess stereoacuity without the need for special glasses, unlike the TNO Stereo test. Since normal stereoacuity in 5-year-old children is approximately 100 arcsec [26] and the Lang II Test measures up to 200 arcsec, we considered it sufficient for this purpose. However, it is not suitable as a standalone screening test [26–28]. It was included in our study as it was already used in ophthalmological clinics in Denmark and within the Healthcare System of Greenland. Our results indicate that the Lang II test does not enhance the sensitivity of the vision screening process. Therefore, despite its current use, our findings suggest that it is not a valuable addition to the screening protocol in Greenland.

The overall mean VA for the worse- and best-seeing eye at the examination was 0.05 and 0.01 logMAR, respectively, in accordance with previous studies from other countries [16,29,30]. The mean cycloplegic spherical equivalent measurement from the examination was more hyperopic than observed in Chinese and African-American children but lower than in White-American and Danish children [16,31,32], suggesting genetics and environmental factors might influence the development of refractive errors in children. Consistent with findings from other studies, with-the-rule cycloplegic astigmatism was the most common form identified [33–35]. Studies on myopia in Inuit communities have shown that since the 1950s, the prevalence of myopia has been increasing among young adults and adults. This rise has been attributed to the shift from traditional Inuit lifestyles to more Westernised living rather than genetic factors. With this transition, children now engage in more near-field work, such as reading and other close-up activities, compared to their predecessors. These environmental changes are believed to play a significant role in the development of myopia [36]. In line with this, our study found that 5% of preschool children in Greenland had myopia, which may reflect similar environmental influences on vision. The VA measurements tested during the ophthalmological examinations were poorer than those recorded at the screenings. This discrepancy may be attributed to the different settings; the examinations occurred in a hospital environment where children are typically shy and more nervous, whereas the screenings were conducted in a more familiar kindergarten setting. Additionally, the improvement in stereoacuity observed during the ophthalmological examination could be due to a learning effect. Despite these variations, the screenings successfully identified most children who required ophthalmological care.

The World Health Organization recommends using a VA of $< 6/12$ (>0.3 logMAR) in vision screenings as a threshold for further examination [2]. However, adopting this cut-off would reduce our sensitivity to below 20%, which was considered unacceptable. Analysis of Receiver Operating Characteristic curves showed that the optimal threshold for distance VA was ≥ 0.2 logMAR or an interocular difference in VA of two lines

or more (Figure 5a and Table 2). Sensitivity could be increased to 89% if the decision about referral for examination also included non-cycloplegic autorefraction with the Plusoptix device.

To address concerns about overtreatment and unnecessary expenses for parents, it is important to note that children will only be prescribed glasses after a thorough ophthalmological examination confirms the necessity.

High sensitivity is crucial in Greenland, where consulting ophthalmologists visit towns only once a year. Consequently, the priority is identifying children who require ophthalmological evaluation, as the risk of delaying proper treatment outweighs the concern of referring false positives. Studies have shown that the Plusoptix has a high sensitivity and positive predictive value for identifying children with refractive errors, and performs just as well, sometimes better, than comparable devices such as the Spot and 2Win photoscreeners [37–39].

Our findings indicate that vision screening in the current study using distance VA and non-cycloplegic autorefraction successfully identified nine out of ten children requiring treatment or further follow-up. This underscores the importance of vision screening. However, only one out of three referred children will need treatment or follow-up (Table 2). Incorporating the Plusoptix autorefractor into vision screening identifies half of the children requiring referral to an ophthalmologist who would otherwise pass the screening using distance visual acuity alone. This improvement in sensitivity underscores the importance of advanced technology in ensuring comprehensive vision assessments.

The 95% limits of agreement between the VA measures from the screening and the ophthalmological examination range from approximately −0.25 to 0.20 logMAR. This indicates that the test-retest variability could lead to a reduction in the number of referrals, as patients who initially appeared to require referral might show improved visual acuity on retesting, as shown in other studies [22]. The Plusoptix autorefractor tends to underestimate refraction by approximately 0.40 dioptres. Clinically, this difference is considered negligible and aligns with findings from other studies [11,25].

Adding near VA to distance VA and non-cycloplegic refraction with the Plusoptix increased sensitivity to 94% (Table 2). Near VA was added to the screening process to determine if children with hyperopia, who might otherwise pass distance VA testing, could be identified more easily. However, as the children had difficulty maintaining the testing distance, using near VA for screening proved too inaccurate and is not advisable in a vision screening setting in Greenland.

In the best-case scenario, the cost for the first year is estimated at 395 DKK per child (53 Euros) for 800 children. In subsequent years, the cost drops to 79 DKK per child (11 Euros), primarily due to the one-time expenses incurred in the first year. In the worst-case scenario, with 25% more days to conduct the screenings, the cost rises to 98 DKK per child (13 Euros) for the second year. These figures are comparable to costs in other countries [40–42]. Costs would rise significantly if other healthcare professionals within the Greenlandic healthcare system were used instead of optometrists, as the optometrists cover their own travel expenses. Travelling within Greenland is expensive, with one return ticket from the capital, Nuuk, to one of the other towns ranging from 3,000 to 20,000 DKK (approximately 400 to 2,600 Euros).

While all parents in Greenland receive information about childhood health examinations shortly after the birth of their child, the lack of systematic follow-up may contribute to limited awareness of and low participation rates in vision screenings, as previously reported from Greenland [13]. Limited attention to vision screening programmes is not unique to Greenland [43,44], suggesting that repetition of systematic information about health examination is warranted to increase awareness. As part of this study, a national campaign was launched in Greenland in 2022, targeting teachers, childcare workers, and parents to raise awareness about signs of reduced vision in children, with the goal of emphasising the importance of early detection and intervention [45]. The high turnover rate of healthcare professionals in Greenland challenges the execution of consistent health examinations nationwide. Given their notably low turnover rate, assigning the responsibility for preschool children's vision screening to optometrists could mitigate this issue. Our study demonstrates that optometrists can conduct these screenings effectively.

In conclusion, our findings indicate that most children in Greenland have good visual acuity and display mild hyperopia. Furthermore, our findings contribute to the development of a practical vision screening method tailored to Greenland's healthcare challenges. To improve participation in the vision screening programme, we recommend ongoing dissemination of information. Additionally, enhancing the screening's sensitivity can be achieved by involving Greenlandic optometrists in distance VA measurements alongside Plusoptix autorefraction in kindergartens.

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Disclosure statement

The Plusoptix devices used in this study were independently purchased by the project and were not provided by the manufacturer. Consequently, the manufacturer had no influence or involvement in the design, conduct, or reporting of this study.

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Author contribution

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Data Analysis/Interpretation: ND, IN, HJ.
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