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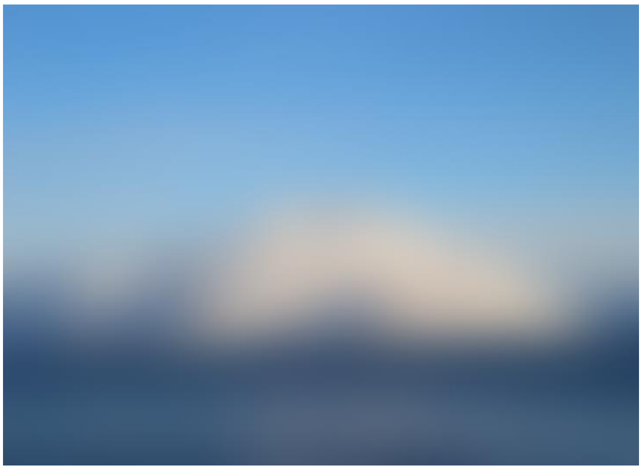

PhD Thesis

Nick Duelund, MD

Vision Screening of Children in Greenland

From Challenges to Solutions

This thesis has been submitted to the Graduate School of Health and Medical Sciences,
University of Copenhagen and Ilisimatusarfik University of Greenland on July 5, 2024

Vision Screening of Greenlandic Children

Evaluating Efficacy, Coverage, and Future Directions

PhD Thesis

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Table of contents

Abbreviations

VA: Visual Acuity

logMAR: Logarith of Minimum Angle of Resolution

WHO: World Health Organization

VI: Vision impairment

D: Dioptres

EMR: Electronic Medical Records

TRV: Test-retest variability

ETDRS: Early Treatment Diabetic Retinopathy Study

UCVA: Uncorrected Visual Acuity

PVA: Presenting Visual Acuity

BCVA: Best Corrected Visual Acuity

SE: Spherical Equivalent

IOD: Interocular difference (in visual acuity)

List of papers

In this thesis, papers will be referenced using Roman numerals.

Paper I

Vision Screening of School Children in Greenland 2017-2022: Coverage and Low Vision Prevalence

Nick Duelund, Ivan Nisted, Ivalu Frederiksen, Marit Eika Jørgensen, Steffen Heegaard, Hanne Jensen

Status: Manuscript submitted on June 12, 2024.

Paper II

Vision Screening and Refraction of Greenlandic Schoolchildren

Nick Duelund, Ivan Nisted, Marit Eika Jørgensen, Steffen Heegaard, Hanne Jensen

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Paper III

Visual Profiling and Vision Screening of Preschool Children in Greenland

Nick Duelund, Ivan Nisted, Marit Eika Jørgensen, Steffen Heegaard, Hanne Jensen

Status: Manuscript submitted on June 3, 2024.

Summary

This thesis presents a comprehensive analysis of vision screening of children in Greenland, focusing on the efficacy of the current programme for six-year-old schoolchildren, the prevalence of vision impairment, amblyopia, and refractive errors among six- and four-year-old children, and the evaluation of a new screening method for preschool children. Additionally, it underscores the challenges of delivering consistent healthcare services in Greenland due to its vast and sparsely populated areas and the lack of prior research on vision health in Greenlandic children.

The thesis involved three populations: two groups of six-year-old children, one with 2,493 children from 2017-2022 and another with 517 children in 2017, and one group of 274 four-year-old children, all born in 2017.

Key findings include an increase in screening coverage of schoolchildren from 43% to 61% from 2017 to 2022, although referral rates to ophthalmologists declined in the same period from 14% to 5% due to system inefficiencies. The prevalence of monocular amblyopia (≥0.3 logMAR) was 2% for both age groups, consistent with European and North American data. The prevalence of vision impairment was steady throughout the study period at 3% for the six-year-old children. Notably, Greenlandic children exhibit less severe vision impairment than other regions, potentially due to genetic or environmental factors. However, they exhibited more hyperopia than African American and Chinese children but less than White American and Danish children. They also had higher myopia rates compared to Danish and indigenous Canadian children.

The thesis highlights the importance of early detection and intervention for optimal visual development, emphasizing a tailored approach for Greenlandic children.

Improvements to the screening programme are suggested, including clear referral instructions, involvement of various healthcare professionals, such as optometrists, and enhanced parental awareness to increase coverage and ensure timely evaluations. It also suggests a new screening method incorporating a non-cycloplegic autorefraction to enhance the sensitivity and effectiveness of preschool children.

Recommendations for screening methods and referral criteria for six- and four-year-olds are provided, along with an outline of the estimated costs of the new screening method. This thesis

provides a basis for helping decision-makers in Greenland improve vision screening for Greenlandic children.

Future research directions include assessing the quality of life of children with vision impairments, exploring the genetic and environmental determinants of myopia, and leveraging technology to improve access to vision care for children in Greenland.

Danish summary (dansk resumé)

Denne afhandling præsenterer en omfattende analyse af synsscreening for børn i Grønland, med fokus på effektiviteten af det nuværende program for seksårige skolebørn, prævalensen af synsnedsættelse, amblyopi (= dovent øje) og brydningsfejl blandt seks- og fireårige børn, samt evalueringen af en ny screeningsmetode for førskolebørn. Derudover understreger den de udfordringer, der er forbundet med at levere kontinuerlige sundhedsydelser i Grønland, på grund af landets store og tyndt befolkede områder, samt manglen på tidligere forskning om synet blandt grønlandske børn.

Afhandlingen inkluderede tre populationer: to grupper af seksårige børn, én med 2.493 børn fra 2017-2022 og en anden med 517 børn i 2017, samt en gruppe af 274 fireårige børn født i 2017.

Vigtige fund inkluderer en stigning i screeningsdækningen af skolebørn fra 43% til 61% i perioden 2017-2022. Dog faldt henvisningsraten til øjenlæger i samme periode fra 14% til 5% på grund af ineffektivitet i det grønlandske sundhedsvæsen. Prævalensen af monokulær amblyopi (≥0,3 logMAR) var 2% for begge aldersgrupper, hvilket er i overensstemmelse med europæiske og nordamerikanske data. Prævalensen af synsnedsættelse var stabil gennem hele studieperioden på 3% for de seksårige børn. Bemærkelsesværdigt udviser grønlandske børn mindre alvorlig synsnedsættelse sammenlignet med andre regioner, potentielt på grund af genetiske eller miljømæssige faktorer. Dog udviste de mere hyperopi (langsynethed) end afroamerikanske og kinesiske børn, men mindre end hvide amerikanske og danske børn. De havde også højere myopi (nærsynethed) forekomst sammenlignet med danske og indfødte canadiske børn.

Afhandlingen fremhæver vigtigheden af tidlig identifikation og intervention for optimal synsudvikling, og understreger vigitigheden af en skræddersyet tilgang for grønlandske børn.

Forbedringer til screeningsprogrammet foreslås, herunder klare henvisningsinstrukser, involvering af forskellige sundhedsprofessionelle, såsom optometrister, og øget opmærksomhed om synsscreening hos forældrene for at øge dækningen og sikre rettidige evalueringer. Afhandlingen foreslår også en ny screeningsmetode, der inkluderer en non-cykloplegisk brillestyrkemåling for at forbedre sensitiviteten og effektiviteten af screening af førskolebørn.

Anbefalinger til screeningsmetoder og henvisningskriterier for seks- og fireårige børn beskrives, sammen med en oversigt over de anslåede omkostninger ved den nye screeningsmetode. Denne afhandling giver et grundlag for at hjælpe beslutningstagere i Grønland med at forbedre synsscreeningen af grønlandske børn.

Fremtidige forskning bør inkludere vurdering af livskvaliteten hos børn med synsnedsættelser, udforskning af de genetiske og miljømæssige årsager til myopiudvikling, og udnyttelse af teknologi til at forbedre adgangen til synsundersøgelse af børn i Grønland.

Introduction

Vision screening is a crucial public health measure designed to detect visual impairments in children at an early stage. The World Health Organization recommends that a vision screening should be conducted at least once between the ages of three and five years[1]. The current recommendations for vision screening in Greenland[2] are adapted from the Danish guidelines[3]. A vision screening is designed to identify children with impaired vision who need treatment before the condition is permanent and untreatable. Amblyopia and significant refractive errors must be treated as early as possible[4].

Impaired vision in children may have different adverse outcomes in their daily lives. It may affect their learning ability, leading to poor academic performance due to difficulties in reading and writing[5]. Children with uncorrected vision problems may also experience delays in developing motor skills and coordination[6,7], which are crucial for physical activities and overall growth. Social interactions may be negatively impacted, as children with vision impairments struggle to engage in play and other activities with their peers, potentially leading to social isolation and low self-esteem[8,9].

In Greenland, the sociocultural and vast geographical context present additional challenges for the implementation and effectiveness of vision screening programmes. The vast and sparsely populated areas make it difficult to provide consistent and comprehensive healthcare services, including vision screenings. Additionally, there is limited access to specialised eye care professionals and facilities, further complicating the timely diagnosis and treatment of visual impairment in children. Addressing these challenges requires a tailored approach that considers the needs and conditions of the Greenlandic population.

As there is a lack of prior research on vision health in Greenlandic children, this thesis aims to address this knowledge gap by assessing the prevalence of vision impairment and amblyopia and developing recommendations for future vision screening practices for Greenlandic children. This thesis may provide a basis to help decision-makers in Greenland improve vision screening for Greenlandic children.

Background

The maturation of vision and visual acuity

A newborn child's vision is not fully developed at birth but matures throughout childhood. Vision results from a complex interaction between various parts of the eye, such as the retina and the optic nerve, and the brain, particularly the visual pathways and the visual cortex located in the posterior part of the brain. The development of vision during childhood is, therefore, a complex interplay involving different parts of the eye and the brain.

During the first year of a child's life, vision matures from being able to only observe single targets at birth to the capability to assess objects at different distances by age one[10]. The fovea, the central part of the retina responsible for high-resolution vision, is fully developed by around 13 years[11]. The visual cortex reaches a level of development comparable to that of adults by approximately the age of four years[12].

Visual acuity (VA) is a term used to describe the clarity of vision. In adults, VA is usually measured with letters, while symbols are often used for children. However, this approach is not feasible for young children. Instead, preferential looking is used, where VA is measured objectively in cycles per degree, for instance, using Teller Acuity Cards.

Visual acuity evolves rapidly during the first year of life. Around the first week of life, VA is approximately one cycle per degree. By age one year, VA is around nine cycles per degree[13,14], equivalent to 0.32 in Snellen decimals or 0.5 logarithm of the Minimum Angle of Resolution (logMAR). An adult level of VA, around 32 cycles per degree (equivalent to around 1.0 Snellen decimal or 0.0 logMAR), is acquired by age five years[15].

Early detection and intervention for visual impairments are crucial for optimal visual development.

Vision screening

In 1899, the first state-supported vision screening in schools was introduced in Connecticut, USA[16]. Since then, vision screening has been implemented in many countries. The methodology has also evolved, incorporating different visual acuity charts and, at times, including a test for strabismus. In Denmark, preschool vision screening was introduced in 1946[17], while Greenland officially first implemented vision screening of children in 2005 by specifying the legislative text[2]. Although the World Health Organization (WHO) has provided recommendations on when to conduct vision screening and failure cut-offs for these screenings[1], many countries continue to employ different methodologies[18].

Before the introduction of mass screening for a population, specific criteria must be considered. These criteria are known as Wilson & Jungner's principles, as illustrated below[19]:

1. The condition sought should be an important health problem.
2. There should be an accepted treatment for patients with recognised disease.
3. Facilities for diagnosis and treatment should be available.
4. There should be a recognisable latent or early symptomatic stage.
5. There should be a suitable test or examination.
6. The test should be acceptable to the population.
7. The natural history of the condition, including development from latent to declared disease, should be adequately understood.
8. There should be an agreed policy on whom to treat as patients.
9. The cost of case-finding (including diagnosis and treatment of patients) should be economically balanced in relation to possible expenditure on medical care as a whole.
10. Case-finding should be a continuing process and not a "one and for all" project.

The vision screening programme in Greenland essentially fulfils Wilson & Jungner's principles. The programme is designed to identify children with impaired vision, usually due to refractive errors or amblyopia. The natural history of these two conditions is well known, and they can significantly affect a child's development, education, and quality of life. These conditions also have identifiable symptoms at early ages, and effective treatments are available, thereby fulfilling principles 1, 2, 4, and 7. As there is a screening programme in Greenland, facilities for diagnosis and treatment are available and acceptable to the public, given the non-invasive nature of the method. However, not all towns in Greenland may have access to all necessary facilities. Additionally, there is an agreed policy on how to conduct the screening, fulfilling principles 3, 5, 6, 8, and 10. The cost-effectiveness of the vision screening programme in Greenland has not been studied in recent years. However, studies from England, the Netherlands, and Romania have shown that vision screening is cost-effective[20]. American studies have also demonstrated that vision screening is highly cost-effective compared to other health care interventions[21]. Additionally, establishing a vision screening programme for four- to five-year-old children is more cost-effective than a similar programme for two-year-olds[22]. Given these findings from other countries, it is reasonable to assume that the vision screening programme in Greenland could also be cost-effective.

Vision impairment

Vision impairment (VI) refers to a significant reduction in vision, varying from mild visual loss to blindness. The World Health Organization categorises vision impairment into different categories based on the degree of visual acuity in the better-seeing eye[23]:

Mild vision impairment	VA >0.3 to ≤0.5 logMAR
Moderate vision impairment	VA >0.5 to ≤1.0 logMAR
Severe vision impairment	VA >1.0 to ≤1.3 logMAR
Blindness	VA >1.3 logMAR

The causes of vision impairment in childhood globally vary and include congenital cataract, congenital glaucoma, retinopathy of prematurity, trachoma, and refractive error.

The estimated global prevalence of VI in children under 14 years of age in 2020 was 1.4 million who are blind, 22.2 million with moderate to severe VI, and 46.6 million with mild VI[24]. Higher prevalence is observed in rural areas, among indigenous people, and in populations with lower socioeconomic status[24].

Studies have shown that children with VI have a lower quality of life in terms of mental and social well-being. They tend to have fewer friends, experience greater loneliness, and engage in less physical activity than their peers without VI[25]. This social isolation can increase feelings of exclusion and affect their overall development and happiness. The impact of VI extends to the family, with parents often experiencing significant mental stress due to caregiving demands and concerns for their child's future. Providing support and resources can greatly reduce parental stress and improve their ability to support their child effectively[26,27].

Accessible vision screening and supportive measures for all children, including those in rural areas, are crucial for the early identification of vision impairment, enabling timely support, treatment, and the provision of necessary aids, educational resources, and personal assistance for their daily lives.

Amblyopia

Amblyopia is a condition characterised by impaired visual acuity in one or both eyes; most frequently, it affects only one eye. It originates from a developmental issue in the visual system during early childhood due to a lack of normal visual pattern exposure[28]. Even though no obvious pathology is apparent in the impaired vision, certain conditions predispose an individual to amblyopia. These include refractive errors, such as anisometropia, strabismus, and opacifications, like corneal scarring or cataract[29]. As amblyopia is often not noticeable to parents or healthcare professionals, vision screening is recommended to identify children who may have the condition.

Globally, the prevalence of amblyopia ranges from 1% to 3%, the highest rates observed in high-income countries[30]. The prevalence of amblyopia in Greenland is unknown.

The treatment for amblyopia involves either patching or administering atropine eye drops to the unaffected eye to force the brain to use the affected eye, compensating for the previous lack of normal visual pattern exposure. Randomised controlled trials have demonstrated that patching and atropine eye drops are equally effective in treating amblyopia[31]. Studies on patch treatment dosage have also been conducted[32,33].

Care must be taken when discontinuing patch treatment, as up to one-fourth of children may experience a recurrence of amblyopia if treatment is stopped abruptly after six hours of daily patching. Gradually reducing to two hours per day before cessation can help minimise the risk of recurrence[34]. With successful treatment, the improved vision can be sustained until adolensence[35].

If left untreated, amblyopia may result in permanent vision impairment in the affected eye. Amblyopia may negatively impact an individual’s life at various stages. In childhood, it is associated with a lower quality of life compared to children without glasses[9]. In teenagers, amblyopia may lead to lower self-esteem, slower reading speed, and poorer motor skills[36]. In adulthood, individuals with amblyopia are less likely to complete higher education and have a higher risk of injuring their better-seeing eyes than those without amblyopia[37]. Amblyopia treatment should ideally begin before age seven years, with optimal outcomes likely if started before age five years[4]. Hence, preschool vision screening is essential, as it helps to detect and address vision problems early, ensuring timely intervention and better visual outcomes for children.

Refractive errors

Refractive errors are a group of conditions that cause blurred vision. The eye is spherical in shape, and light is bent (refracted) by the curvature of the cornea and the lens. This bending directs the light precisely onto the fovea, the central part of the retina responsible for high-resolution vision. If the light focuses in front of the fovea, it results in myopia, causing distant objects to appear blurry. Conversely, if the light focuses behind the fovea, it leads to hyperopia, making nearby objects appear blurry. In case the curvature of the cornea or lens is irregular, light is focused unevenly, resulting in astigmatism, which causes blurred vision at all distances. Anisometropia, a condition with a significant difference in the refractive power between the two eyes, can also lead to blurred vision.

Most newborns are hyperopic up to +4 dioptres (D) and gradually become emmetropic around age six[38,39].

Globally, it is estimated that 123 million people have moderate to severe vision impairment due to uncorrected refractive error[40].

In recent years, there has been a notable increase in the number of school children developing myopia, a trend that raises concerns for future vision health[41,42]. The prevalence of refractive errors among Greenlandic children is unknown.

Untreated refractive errors may lead to vision impairment or even amblyopia. Studies have shown that children with uncorrected refractive errors tend to have lower educational performance and poorer reading skills than their emmetropic peers. Additionally, correcting these errors with glasses not only improves academic performance but also enhances the child's overall mental health and well-being[43]. Therefore, vision screening is crucial to identify and address these issues early in life.

Setting

Even though Greenland is the biggest island in the world, covering 2.2 million square kilometres, the population only consist of around 56.000 inhabitants. The inhabitants are predominantly Inuit of origin and reside along the coastline in 17 towns, around 60 settlements, and over 80% reside in towns[44]. As no residential areas are connected by roads, all travel must be done by aeroplane/helicopters or boats. All towns and larger settlements have primary schools. Despite Greenland's autonomy, complete with its own parliament and Greenlandic as the official language, its social and health policies are predominantly influenced by Danish viewpoints. Greenland's healthcare system is run by the government and is publicly funded, and medical treatment, including medicine, is free of charge for the public. Patients with specific ophthalmological conditions (i.e. high hyperopia, myopia, or astigmatism) can be given glasses free of charge. The rest of the public must pay for the glasses themselves. The healthcare system is divided into five regions, as illustrated in **Figure 1**: Avannaa (Northern Greenland), Qeqqata (Mid-Greenland), Qeqertalik (West Greenland), Sermersooq (The Capital and East Greenland), and Kujataa (Southern Greenland). Each region contains a regional hospital, which functions as a primary healthcare centre, while the capital hosts the National Hospital, where more specialised care is available.

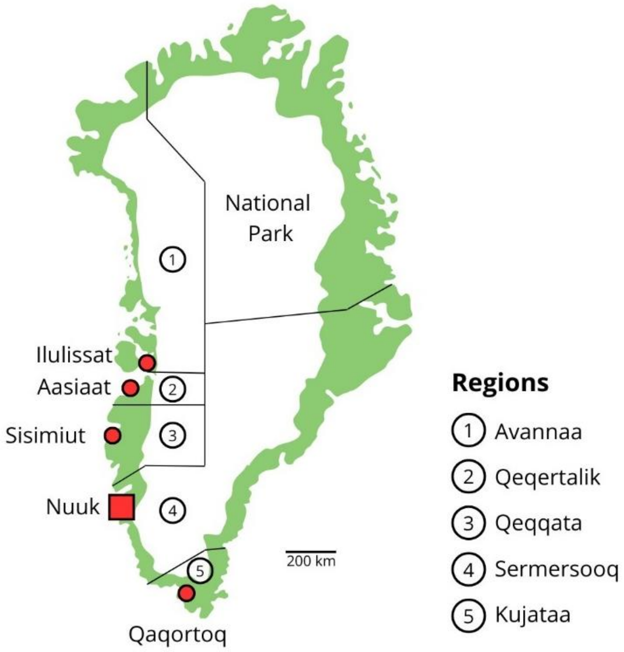

Figure 1: Map of Greenland highlighting the five regions and the locations of towns with regional hospitals (red circle) and the capital (red square) (III).

Ophthalmological care in Greenland

There are no permanent ophthalmologists in Greenland.

Consultants from Denmark visit each town once a year for up to two weeks to conduct medical ophthalmological examinations. A cataract team annually visits the regional hospitals to treat cataract surgically. The capital is visited annually, or every other year, by surgeons to treat strabismus, diseases on the retina, or diseases on the eyelids or tear duct. Outside these visits, all ophthalmological examinations are conducted through telemedicine, where nine towns have the same equipment. Using telemedicine, the patients can have their visual acuity and intraocular pressure measured along with a photography of their retina combined with an Optical Coherence Tomography image of the retina. These measurements are digitally transmitted to the ophthalmologists in Copenhagen, who then evaluate what the treatment should be, if the patient should be seen by an ophthalmologist in their next visit to the patient's town or nearest regional hospital, or if the patient should be referred to the Department of Ophthalmology at Rigshospitalet in Denmark for further evaluation or treatment. The local doctors can consult with an ophthalmologist in Denmark by phone for any acute cases.

Vision screening in Greenland

The Government of Greenland recommends a series of general health examinations of all children in Greenland, including visual health[2]. Five weeks after birth, it is recommended to examine for congenital cataract by the local doctor (Red Reflex Test).

The first vision screening is recommended at the age of four years by a local doctor and the next at the age of six years by a school nurse. As of 2024, Nuuk and Sisimiut have permanent school nurses, while the other three regional hospitals employ temporary ones. In towns and settlements outside these regions, school nurses from regional hospitals travel to conduct children's health examinations. In most larger towns, healthcare assistants also fulfil this role when school nurses are unavailable. However, not all towns and settlements are visited annually due to a shortage of permanent staff and travel issues caused by bad weather and sea ice.

Hypotheses

Based on the background information outlined, the overall aim of this thesis is to evaluate the efficacy and coverage of the current vision screening programme for schoolchildren in Greenland, examine the prevalence of vision impairment and refractive errors among Greenlandic school and preschool children, and to assess a new screening method for preschool children conducted by professionals not previously involved in vision screening in Greenland. The thesis investigated the following propositions:

- The coverage of participants in Greenland's current vision screening programme is inadequate compared to other Inuit communities and Scandinavian countries.
- The current vision screening programme fails to identify all children who require ophthalmological evaluation.
- Not all children identified with vision impairment in a vision screening are consistently referred to an ophthalmologist for further evaluation
- The prevalence of amblyopia and severe visual impairment is higher in Greenland compared to Denmark and Canada/USA.
- Due to evolutionary factors, Greenlandic Inuits have been thought to exhibit higher instances of hyperopia and astigmatism. Consequently, the prevalence of such refractive errors is higher in Greenlandic children compared to their peers in Denmark and Canada/USA.
- Myopia is not prevalent among preschool children in Greenland, as is also the case in Denmark.

Objectives

To assess our hypotheses, we explored the following objectives:

- To describe the participation rate and the referral rate of the current vision screening programme of six-year-old school children in Greenland from 2017 to 2022.
- To estimate the prevalence of vision impairment among six-year-old school children.
- To estimate the prevalence of amblyopia and refractive errors among six-year-old school children in Greenland.
- To describe normative data on visual acuity and refraction among four-year-old children
- To evaluate the efficacy of a new vision screening method for six-year-old school children.
- To assess a new vision screening method for preschool children in Greenland.

Materials and methods

Study design

This thesis is based on register and cross-sectional studies involving three different study populations:

- A register study of six-year-old children in Greenland from 2017 to 2022, utilizing electronic medical records (I).
- An in-depth descriptive cross-sectional study of six-year-old children in Greenland during the school year 2017/2018 (II) with follow-up in 2023 in the electronic medical records of children seen by an ophthalmologist.
- A comparative cross-sectional study of four-year-old kindergarten children in six towns in Greenland. A follow-up in the electronic medical records of children referred to an ophthalmologist was conducted within one year after referral. This study involved vision screenings by optometrists at the kindergartens, followed by complete eye examinations by an ophthalmologist at the hospitals (III).

Discussion

A MeSH search in PubMed using the following keywords in various combinations: Child, Preschool Child, Arctic, Greenland, Visual Acuity, Vision Screening, Refraction, Ocular, yielded no results, indicating that the vision of Greenlandic children has not been previously studied. To gain an idea of the current vision health of Greenlandic children, a cross-sectional study is essential to estimate prevalence and to create normative data, which can serve as a basis for future studies[45]. However, no causal conclusions can be drawn due to the cross-sectional study design.

Study population and data collection

This thesis is based on two age groups of Greenlandic children:

- Six-year-olds.
- Four-year-olds.

The six-year-old children were divided into two study populations.

The first population (I) consisted of all children, who turned six years old each year from 2017 to 2022 (i.e. first grade of public school). Only children with a visual acuity measurement recorded in the National Electronic Medical Records (EMR) in Greenland during their first grade at a public school were included. These VA measurements were conducted by school nurses or healthcare assistants throughout Greenland as part of the children's regular health examination. The exclusion criterion was the absence of VA measurements in the EMR (n=31). A total of 2493 children were included. Clinical data for children with a VA of 0.2 logMAR or worse were also extracted and analysed. The starting date was 2017, when Greenland introduced the new EMR to all towns and settlements in the summer of 2017. This made nationwide data extraction possible. Before 2017, a different EMR was used in Greenland, making systematic data extraction impossible. Data extraction from the EMR took place in December 2023.

The second population (II) consisted of children in the first grade of a public school in 2017 for a more thorough assessment as part of the regular health examination in the first grade in public schools. No children were excluded. However, due to the lack of school nurses in four towns and the adjacent settlements, only 517 out of 760 eligible children were included. Data collection took place between September 2017 and October 2018. In 2023, a follow-up in the EMR was conducted to determine how many children were seen by an ophthalmologist and were prescribed glasses.

The principal investigator recruited four-year-old children (III) from kindergartens in six representative towns. These towns were selected to include three with local optometrists and three without, spanning four of Greenland's five regions. By choosing large towns, the study aimed to cover as many children as possible within the limited study period. The exclusion criterion was ongoing contact with an ophthalmologist (n=16). A total of 532 children were eligible to participate in these six towns. Of those, 313 children were included in the study. However, only 274 children participated in both the vision screening and the ophthalmological evaluation, forming the basis for the study population. All children needing glasses, or a new ophthalmological evaluation were referred to an ophthalmologist, and one-year follow-up data were available. Data collection took place between November 2021 and February 2023.

To detect a difference in refractive measurements between cycloplegic refraction, with a mean population value of 0.75 D, and non-cycloplegic refraction, with a mean study group value of 0.60 D, at a significance level of 0.05 and with a power of 0.8 ($\beta = 0.2$), a total of 126 participants in the four-year-old group need to be included in the study.

Discussion

No information about the non-participating children could be retrieved for all three study populations. This absence of data could potentially introduce selection bias if non-participants are more likely to have ophthalmological conditions. However, it is also possible that the non-participants whose parents declined the invitation may be healthy children. Therefore, this potential bias may not significantly affect the overall results. The inclusion of six towns in the four-year-old study was strategic, selecting towns that are geographically spread across Greenland to ensure representation from different regions of the country.

The visual acuity measurements were performed by various personnel, which could introduce inconsistencies in measurement techniques and accuracy, potentially affecting data reliability. However, both personnel groups received appropriate training before the study, which minimised this variability. This thesis includes a large sample size, strengthening the findings' robustness.

Screening methods

School nurses conducted data collection for the second population of six-year-old children. Prior to this, all participating school nurses attended a two-day course on paediatric ophthalmology, which included training on how to conduct vision screening. A paediatric ophthalmologist assessed all results. Children with a VA of 0.2 logMAR or worse or an interocular difference of two lines or more were then referred for an ophthalmological evaluation.

The four-year-old children underwent two examination days. The first examination was a vision screening conducted by an optometrist at the kindergarten. The second examination, carried out by the principal investigator, occurred at the hospital one to seven days after the initial screening. Before the vision screenings, all participating optometrists received detailed verbal instructions on the screening procedures.

In 2017, Greenland introduced a new vision screening tool, the multiline HOTV chart (Precision Vision, Illinois, USA). Since then, it has been used for vision screening of school children, beginning with first-grade pupils. This chart was used for all six-year-olds in this thesis. For the four-year-old children, the multiline Kay Pictures chart was used (Kay Pictures LTD, Hertfordshire, UK). Both the HOTV and Kay Pictures charts are logMAR charts. The HOTV chart was used for the six-year-olds from the second population for near VA measurement, while the Lea Symbols (Lea Test Intl, LLC, Pennsylvania, USA) were used for the four-year-old

children. Additionally, stereoacuity was measured using the Lang II Test (Lang-Stereotest AG, Küsnacht, Switzerland), and non-cycloplegic refraction was measured using the Plusoptix A12R (Plusoptix GmbH, Nuremberg, Germany).
The four-year-old children also received an ophthalmological examination by the same ophthalmologist. The examination mirrored the screening assessments and included additional tests for strabismus, a slit lamp examination, ophthalmoscopy using cycloplegia, and autorefraction using cycloplegia (30 minutes after administering two drops of 1% Cyclopentolate) using a handheld Nidek HandyRef-K autorefractor (Nidek Co. Ltd., Gamagori, Japan).

Discussion

Before introducing the HOTV chart in Greenland, the Østerberg picture chart was used in Greenland to assess the VA of children. Østerberg is a Snellen-based chart[46], while the HOTV is a logMAR-based chart. The difference between these two charts is that the Snellen chart has inconsistent spacing between lines and figures, as the number of figures increases with higher demands for visual acuity. Thus, the crowding effect is influenced by these variations in figure size and spacing. This is not the case with logMAR charts. Snellen-based charts have been shown to underestimate VA measurements compared to logMAR-based charts, especially with worse VA[47,48], and a lower test-retest variability (TRV)[49]. The current 'Golden Standard' for measuring VA is with the Early Treatment Diabetic Retinopathy Study (ETDRS) chart. However, this chart is unsuitable for children, who often struggle to complete it compared to the HOTV chart[50]. Hence, for this thesis, the logMAR-based HOTV chart was chosen. In this thesis, the Kay Pictures chart was chosen for the four-year-old children for the following reasons: First, Kay Pictures had been used for small children in an ophthalmological setting in Greenland before this study commenced. Second, although the Kay Pictures can present better VA in children compared to ETDRS or other charts[51], this difference has been shown to have minimal clinical significance in children with normal vision (i.e. a screening setting), and the TRV has been shown to be good[52]. Third, Kay Pictures have demonstrated very high testability in children aged four years[53]. The Lea Symbols chart was selected for measuring near VA in the four-year-old group as suitable and durable Kay Pictures near VA charts were unavailable due to supply issues caused by the COVID-19 pandemic. However, as the children struggled to keep the testing distance at 40 cm, the accuracy of near visual acuity turned out to be an unreliable method for screening.

The Lang II Test was chosen as it provides an easy way to assess stereoacuity without requiring special glasses. It was included to determine if the sensitivity of the vision screening could be increased, although it should not be used as a standalone vision screening tool due to its low sensitivity[54,55].

Photoscreeners are being increasingly adopted in various parts of the world as part of vision screening for children. Different companies have developed various photoscreeners, all of which measure non-cycloplegic refraction. Studies have shown that Plusoptix has a high sensitivity and positive predictive value for identifying children with refractive errors and reasonable agreement with cycloplegic refraction[56–58]. Additionally, studies comparing Plusoptix with other photoscreeners, such as the Spot and the 2Win photoscreeners, indicate that Plusoptix performs just as well and sometimes even outperforms the others[59–61]. For these reasons, the Plusoptix was chosen for this thesis. The Plusoptix device uses infrared technology to measure refraction, employing a transillumination test similar to that used in retinoscopy with the help of 54 LED illuminations[62].

Definition of Vision impairment

In this thesis, visual acuity is presented as logMAR.

Vision impairment in this thesis was defined as a VA of ≥0.3 logMAR in the better-seeing eye.

Discussion

Even though the WHO defines vision impairment as a VA of >0.3 logMAR in the better-seeing eye[23], various scientific papers use different definitions. As Yekta et al.[63] illustrate, the definition cut-off for VI ranges between ≥0.3 and 0.5 logMAR. The method of measurement is also important to note. The VA measurement can be conducted using one of three methods: Uncorrected Visual Acuity (UCVA), which is VA without corrective glasses; Presenting Visual Acuity (PVA), which is VA with ordinary glasses or without glasses in a person not known to have refractive errors; or Best Corrected Visual Acuity (BCVA), which is VA measured after recent corrective glasses have been applied. In this thesis, UCVA will not be used. As this thesis focuses on vision screening, PVA will be used. However, VA measurements after ophthalmological examinations within the follow-up period will be referred to as BCVA.

The reason for choosing the cut-off of VA of ≥0.3 logMAR was based on the following: Firstly, to simplify the process for clinicians in Greenland, as they only need to know one value on the visual acuity chart for both amblyopia (worse-seeing eye) and vision impairment (better-seeing eye). Secondly, to enable comparisons of the findings from this thesis with other international studies. Due to the different cut-offs, various levels of VA will be used in this thesis to facilitate comparisons of the prevalence of vision impairment.

Definition of Amblyopia

There is no international consensus on the definition of amblyopia regarding VA or refractive measurements. In this thesis, amblyopia was defined as a VA of 0.3 logMAR or poorer in one or both eyes. The following table is an example of different definitions used in scientific papers:

Paper	Monocular Amblyopia	Binocular Amblyopia
American Academy of Ophthalmology[64]	IOD of two or more lines with the better eye within the normal range	**Age 4-5 years:** VA >0.4 logMAR **Age ≥5 years:** VA >0.3 logMAR
Sandfeld et al., 2018[65]	IOD of two or more lines OR a VA of >0.3 logMAR	
Repka et al., 2020[66]	**Age 4 years:** >0.3 logMAR **Age 5-6 years:** >0.2 logMAR	
Multi-Ethnic Pediatric Eye Disease Study Group[67]	IOD of two or more lines with BCVA of >0.1 logMAR AND at least one of the following: *Strabismus* *History of strabismus* *Anisohyperopia ≥1.0 D* *Anisomyopia ≥3.0 D* *Anisoastigmatism ≥1.5 D* *Visual axis obstruction*	**Age >4 years:** BCVA >0.3 logMAR

IOD = Interocular difference
VA = Visual Acuity
BCVA = Best-Corrected Visual Acuity
logMAR = logarithm of Minimal Angle of Resolution

Discussion

The definition of amblyopia in this thesis was selected for two primary reasons. First, it facilitates comparisons with other countries without the need for refractive measurements, given that vision screening in Greenland traditionally includes only VA measurements for distance. This approach enables the evaluation of amblyopia prevalence over multiple years. Second, maintaining simple definitions allows for more straightforward diagnoses in Greenland’s clinics. This is particularly important, considering Greenland does not have permanent ophthalmologists, and general practitioners are the primary contacts for ophthalmological patients. Furthermore, this thesis will present multiple prevalence estimates to enable comparison with other studies that employ different definitions.

Definitions of Refractive errors

Refractive errors are presented as spherical and cylindrical values and spherical equivalents (SE). The cylindrical values are presented as minus cylinders. The SE was calculated as the spherical value plus half of the cylindrical value (spherical value + ½ x cylindrical value). The following table presents the cut-offs used to define refractive errors in this thesis:

Condition	Definition (cut-off values in dioptres (D))
Myopia	≤-0.5 D
Hyperopia	>+2.0 D
Anisometropia	≥1.0 D
Astigmatism	≤-1.0 D
Astigmatism axis	
With-the-rule	0-15 and 165-180 degrees
Oblique	16-74 and 106-164 degrees
Against-the-rule	75-105 degrees

Discussion

There is also no international consensus within the scientific community on the cut-off values for diagnosing myopia, hyperopia, astigmatism, or anisometropia in children. Some report spherical values, while others report spherical equivalents. For instance, some studies define myopia as a refraction of ≤0.5 Dioptres (D)[68], while others define it as <0.5 D[65]. The same goes for hyperopia (>+2.0 D[65], SE ≥+2.0 D[69] or SE +2 to +5 D[70]), astigmatism (≤-0.25 D[71], <-1.0 D[65]), and anisometropia (≥1.0 D[72] or ≥1.5 D[73]). This makes comparison with other countries difficult. By choosing the cut-offs mentioned above, comparisons are simplified. However, multiple cut-offs will be used to compare with other countries.

Ethical considerations

The Greenlandic population is small, making thorough ethical considerations crucial when conducting research. As this thesis was based on screening, ensuring no harm to the children was important. The methodology of this thesis was non-invasive, except for one study population where cycloplegic eye drops were used. These eye drops were necessary to adequately evaluate a new screening method and conduct a thorough eye examination. Given their transient and safe effect, their use was considered acceptable.

The principal investigator, a native Greenlander, anchored this thesis in Greenland by conducting the studies in Greenland, and being enrolled at Ilisimatusarfik University of Greenland as the primary university. Communication with the participants was conducted in their native language, Greenlandic. All written information was provided in both Greenlandic and Danish. Prior to participation, informed consent was obtained from the parents or guardians, ensuring full awareness of the study's objectives, procedures, and potential risks.
The collaborating optometrists, also native Greenlanders, ensured cultural and linguistic alignment and local engagement. Results from the examinations were communicated to the parents in Greenlandic or Danish at the end of the examination.
The studies adhered to the Declaration of Helsinki and were approved by the Greenland Science Ethics Committee (ID-numbers 2023-15841 and 2023-20891), the Greenlandic Health Service, and the Municipalities in the regions visited in Greenland.

Statistics

The distribution of data was evaluated using histograms or QQ plots. Minor deviations from perfect normality were considered negligible due to the large sample size.
Normally distributed continuous data were summarised as mean with standard deviation (SD) or range, while medians with interquartile range (IQR) were used to summarise non-normal data. Categorical data was tested using a non-parametric χ^2-test or Fischer's exact test.
Proportions were presented as percentages with 95% confidence intervals (CI), computed using the normal approximation. Differences in measurements between screening and ophthalmological examination were examined with paired t-tests for normally distributed data, while the Stuart-Maxwell test was used for categorical data. Receiver Operating Characteristics (ROC) and Area Under the Curve (AUC) were calculated for non-categorical data to analyse sensitivity and specificity. The results of these calculations were used to determine the optimal cut-offs using the Plusoptix autorefractor for maximising sensitivity in the detection of significant refractive errors, without excessively compromising specificity. To assess the effectiveness of the vision screening methods in identifying the need for ophthalmological referral, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. However, due to the study design for the second population of six-year-old children, sensitivity, specificity, and NPV could not be calculated, as not all children underwent reexamination with cycloplegic refraction.

Results

Coverage of vision screening of schoolchildren

A total of 2,493 children were included in the study period from 2017 to 2022 to assess the coverage of the current vision screening for six-year-old first-grade children in primary schools in Greenland. The coverage was assessed by analysing the participation rate of children. The coverage in 2017 was 43% [95% CI: 42%, 43%] and increased towards the end of the study period 2022 to 61% [95% CI: 61%, 62%]. Notably, the three regions, Avannaa, Qeqertalik and Sermersooq, had consistently low participation rates throughout the years (**Fig. 2**).

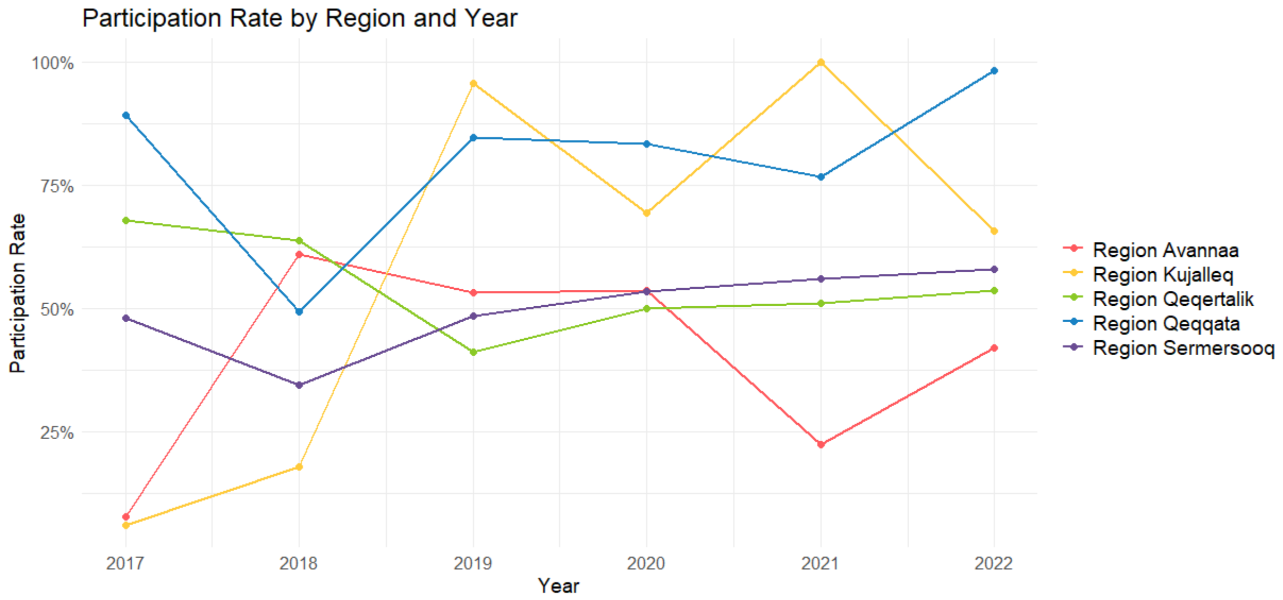

Figure 2: Regional participation rates from 2017 to 2022, highlighting the varying trends in participation throughout the years (I).

In the same period, the proportion of children seen by an ophthalmologist decreased from 14% [95% CI: 10%, 17%] in 2017 to 5% [95% CI: 3%, 7%] in 2022 (**Fig. 3**).

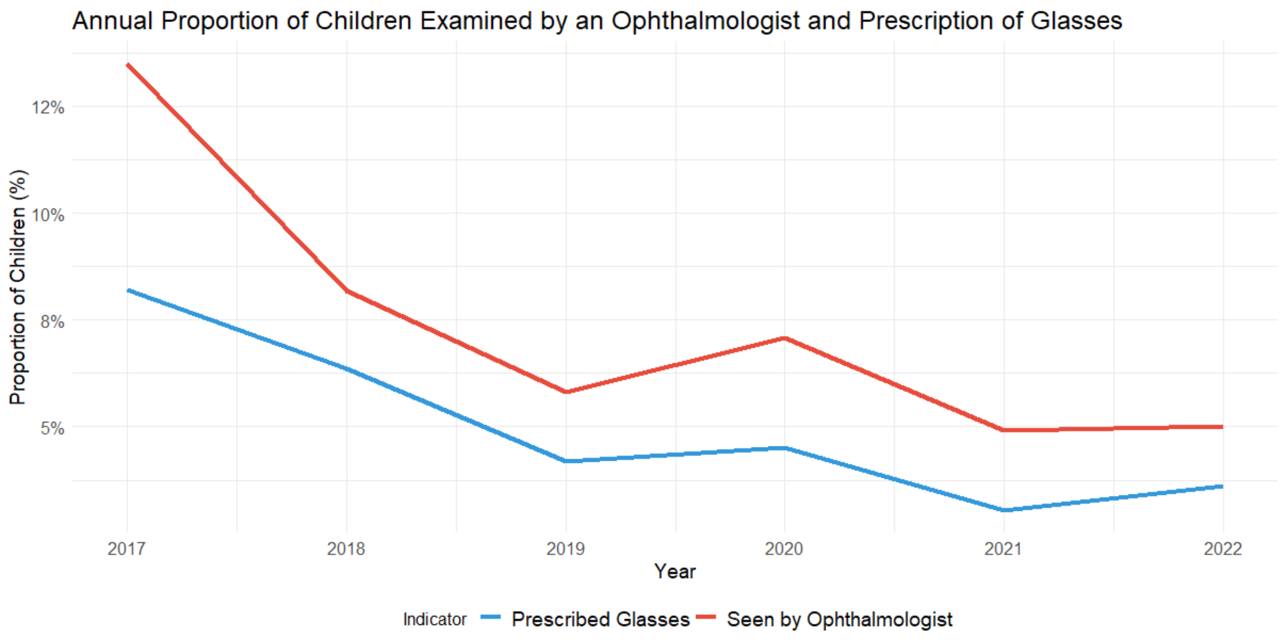

Figure 3: Illustration of the decreasing proportion of children annually seen by an ophthalmologist. The proportion of children prescribed glasses paralleled the proportion of children seen by an ophthalmologist (I).

The referral cut-off to an ophthalmologist in Greenland during the study period was ≥0.2 logMAR. Even so, 57% (n = 221) of the children with a PVA of ≥0.2 logMAR in the worse-seeing eye were not seen by an ophthalmologist. Moreover, of these children, 78% (n = 172) had no further vision screening recorded in their EMR.

Prevalence of vision impairment

The prevalence of vision impairment among six-year-old children (PVA of ≥0.3 logMAR in the better-seeing eye) was 3% [95% CI: 2%, 4%] for the entire study period from 2017 to 2022 and remained relatively consistent each year, ranging from 2% to 5% (I). For four-year-old children, the corresponding prevalence in 2023 was also 3% [95% CI: 1%, 5%].

The prevalence of VI for both age groups varies depending on the definitions used, as illustrated in **Table 1**:

Table 1: Prevalence of vision impairment among six-year-old and four-year-old Greenlandic children when using different cut-offs of presenting visual acuities of the better-seeing eyes from the screening.

	Prevalence with [95% CI]	
PVA cut-off	**Six-year-olds**	**Four-year-olds**
≥0.2 logMAR	9% [8%, 10%]	7% [4%, 10%]
≥0.3 logMAR	3% [2%, 4%]	3% [1%, 5%]
≥0.4 logMAR*	2% [1%, 2%]	1% [0%, 3%]
≥0.5 logMAR	1% [0%, 1%]	1% [0%, 3%]
≥0.6 logMAR	1% [0%, 1%]	0

*WHO criteria for vision impairment
CI = Confidence Interval
logMAR = logarithm of Minimal Angle of Resolution

Prevalence of amblyopia

Among six-year-old children, the prevalence of amblyopia (PVA of ≥0.3) was 7% [95% CI: 5%, 9%] in either eye in 2017, while the prevalence for binocular amblyopia was 3% [95% CI: 2%, 5%]. For BCVA, the prevalence decreased to 2% [95% CI: 1%, 3%] in either eye and 1% [95% CI: 0%, 3%] for binocular amblyopia (II).

Among four-year-old children, the prevalence of amblyopia (PVA of ≥0.3 logMAR) was 7% [95% CI: 4%, 10%] in the worse-seeing eye in 2023 (III).

A total of 44 children (9% of participants) in the six-year-old age group had an interocular difference (IOD) of two or more lines at the screening (PVA). In comparison, 16 children (6% of participants) in the four-year-old age group had an IOD of two or more lines.

Normative data on visual acuity and refraction and prevalence of refractive errors

The presenting visual acuity was approximately 0.00 logMAR in the six- and four-year-olds. However, six-year-olds exhibited slightly poorer PVA in their worse-seeing eye compared to four-year-olds. Additionally, four-year-olds had poorer near PVA than six-year-olds. Both age groups demonstrated good stereoacuity. For both groups, the normative data on refraction indicated mild hyperopia and minimal astigmatism (see **Table 2**).

Table 2: Normative data on visual acuity and refraction for the six- and four-year-old children in Greenland

	Six-year-old children n=517 (II)	**Four-year-old children n=274 (III)**
Distance PVA (logMAR)		
Binocular	0.01 (±0.10)[1]	-0.04 (±0.10)[1]
Worse-seeing eye	0.07 (±0.15)[1]	0.02 (±0.15)[1]
Better-seeing eye	0.02 (±0.10)[1]	-0.02 (±0.11)[1]
Interocular difference	0.0 [0.0, 1.0][2]	0.0 [0.0, 1.0][2]
Near binocular	0.01 (±0.10)[1]	0.11 (±0.14)[1]
Stereoacuity (seconds of arc)	200’’ [200, 200][2]	200’’ [200, 200][2]
Plusoptix Refraction (D)		
Least hyperopic eye	+0.85 (±0.82)[1]	+0.92 (±0.84)[1]
Most hyperopic eye	+1.17 (±0.91)[1]	+1.25 (±0.90)[1]
Most astigmatic eye	-0.75 [-1.50, -0.25][2]	-0.50 [-0.75, -0.25][2]
Spherical equivalent right eye	+0.72 (±0.79)[1]	+0.78 (±0.75)[1]
Spherical equivalent left eye	+0.79 (±0.78)[1]	+0.83 (±0.81)[1]
Cycloplegic Refraction (D)	**n=94**	**n=246**
Least hyperopic eye	+1.25 (±2.47)[1]	+1.28 (±1.24)[1]
Most hyperopic eye	+1.97 (±2.53)[1]	+1.65 (±1.35)[1]
Most astigmatic eye	-0.75 [-1.50, -0.25][2]	-0.50 [-0.75, -0.25][2]
Spherical equivalent right eye	+1.17 (±2.74)[1]	+1.20 (±1.22)[1]
Spherical equivalent left eye	+1.65 (±2.50)[1]	+1.28 (±1.25)[1]

[1]Mean±Standard deviation
[2]Median [Interquartile range]

Among six-year-olds, the prevalence of non-cycloplegic refractive errors was as follows: 10% had hyperopia exceeding +2.0 D, 3% had myopia of -0.5 D or less, and 14% had astigmatism of -1.00 D or less. The corresponding cycloplegic values were 8% for hyperopia (spherical and SE), 4% for myopia (spherical and SE), and 6% for astigmatism.

For four-year-old children, using the same cut-offs as the six-year-olds, the prevalence of non-cycloplegic refractive errors was found to be 13% for hyperopia, 3% for myopia, and 19% for astigmatism. Cycloplegic measurements for this age group indicated that 22% exhibited hyperopia (spherical and spherical equivalent), 5% exhibited myopia (6% with spherical equivalent), and 15% exhibited astigmatism. Notably, with-the-rule astigmatism was most common in cycloplegic refraction among four-year-olds.

Efficacy of the new screening method

The results from various screening tests for six-year-old children in 2017 (II) were analysed by calculating the PPVs, as illustrated in **Table 3**.

Table 3: Positive predictive values of different screening tests for the prescription of glasses for the six-year-old Greenlandic children (II).

	PPV
One measurement	
Distance VA ≥0.2 worse eye (logMAR)	0.40 (33/83)
≥2-line difference in VA	0.43 (16/37)
Distance VA ≥0.2 worse eye (logMAR) **&** ≥2-line difference in VA	0.52 (15/29)
Near VA ≥0.2 binocular (logMAR)	0.23 (7/31)
Abnormal Plusoptix‡	0.41 (28/68)
Lang II Test >400’’	0.50 (12/24)
Combining two measurements	
Distance VA ≥0.2 **&** Near VA ≥0.2 binocular	0.37 (7/19)
Distance VA ≥0.2 **&** Lang II Test >400’’	0.64 (9/14)
Distance VA ≥0.2 **&** Abnormal Plusoptix‡	0.57 (21/37)
Near VA ≥0.2 binocular logMAR **&** Lang II Test >400’’	0.50 (3/6)
Near VA ≥0.2 binocular logMAR **&** Abnormal Plusoptix‡	0.55 (6/11)
Lang II Test >400’’ **&** Abnormal Plusoptix‡	0.67 (4/6)
Combining three measurements	
Distance VA ≥0.2 **&** Near VA ≥0.2 binocular **&** Lang II Test >400’’	0.60 (3/5)
Distance VA ≥0.2 **&** Near VA ≥0.2 binocular **&** Abnormal Plusoptix‡	0.67 (6/9)
Distance VA ≥0.2 **&** Lang II Test >400’’ **&** Abnormal Plusoptix‡	0.75 (3/4)
Near VA ≥0.2 binocular **&** Lang II Test >400’’ **&** Abnormal Plusoptix‡	1.00 (2/2)
Combining all four measurements	
Distance VA ≥0.2 **&** Near VA ≥0.2 binocular **&** Lang II Test >400’’ **&** Abnormal Plusoptix	1.00 (2/2)

Using only one test, the distance VA measurement had the highest PPV. Combining this with other tests, such as the Plusoptix or Lang II Test, increased the PPV; however, the absolute number of children with prescribed glasses decreased considerably when adding a third or a fourth test.

Two different calculations were performed for the four-year-old children (III) to evaluate the screening tests. In one approach, combining multiple tests required that all criteria should be met.

For example, a child must have both low VA and an abnormal Plusoptix measurement (see **Supplementary 1**). This approach resulted in lower sensitivity than the alternative approach, where the presence of only one abnormal measurement from any of the other tests was sufficient (**Table 4a** and **Table 4b**).

Table 4a: Sensitivity and specificity of different screening tests of four-year-old Greenlandic children for referral necessity (III).
Cut-offs used: VA of 0.2 logMAR and abnormal Plusoptix‡

	Sensitivity	**Specificity**
One measurement		
Distance VA*	0.72 (23/32)	0.91 (220/242)
Near VA ≥0.2 binocular (logMAR)	0.47 (15/32)	0.77 (187/242)
Abnormal Plusoptix‡	0.53 (17/32)	0.78 (189/242)
Lang II Test >400’’	0.28 (9/32)	0.93 (226/242)
At least one abnormal result of two measurement		
Distance VA* **OR** Near VA ≥0.2 binocular	0.81 (26/32)	0.72 (175/242)
Distance VA* **OR** Abnormal Plusoptix‡	0.89 (28/32)	0.70 (171/242)
Distance VA* **OR** Lang II Test >400’’	0.72 (23/32)	0.88 (213/242)
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)
Distance VA* **OR** Near VA ≥0.2 binocular **OR** Lang II Test >400’’	0.84 (27/32)	0.68 (164/242)
Distance VA* **OR** Lang II Test >400’’ **OR** Abnormal Plusoptix‡	0.88 (28/32)	0.66 (159/242)
At least one abnormal result of four measurement		
Distance VA* **OR** Near VA ≥0.2 binocular **OR** Lang II Test >400’’ **OR** Abnormal Plusoptix‡	0.94 (30/32)	0.55 (125/242)

*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
VA = Visual Acuity
logMAR = logarithm of Minimum Angle of Resolution
’’ = Seconds of arc

Table 4b: Positive (PPV) and negative (NPV) predictive values of different screening tests of four-year-old Greenlandic children for referral necessity (III).

Cut-offs used: VA of 0.2 logMAR and abnormal Plusoptix‡

	PPV	NPV
One measurement		
Distance VA*	0.51 (23/45)	0.96 (220/229)
Near VA ≥0.2 binocular (logMAR)	0.21 (15/70)	0.92 (187/204)
Abnormal Plusoptix‡	0.24 (17/70)	0.93 (189/204)
Lang II Test >400’’	0.36 (9/25)	0.91 (226/249)
At least one abnormal result of two measurement		
Distance VA* **OR** Near VA ≥0.2 binocular	0.28 (26/93)	0.97 (175/181)
Distance VA* **OR** Abnormal Plusoptix‡	0.29 (28/99)	0.98 (171/175)
Distance VA* **OR** Lang II Test >400’’	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‡	0.22 (30/138)	0.99 (134/136)
Distance VA* **OR** Near VA ≥0.2 binocular **OR** Lang II Test >400’’	0.26 (27/105)	0.97 (164/169)
Distance VA* **OR** Lang II Test >400’’ **OR** Abnormal Plusoptix‡	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’’ **OR** Abnormal Plusoptix‡	0.20 (30/147)	0.98 (125/127)

*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
VA = Visual Acuity
logMAR = logarithm of Minimum Angle of Resolution
’’ = Seconds of arc

Using one screening test, the distance VA measurement had the highest sensitivity and PPV, along with good specificity and NPV. When combining multiple measurements, distance VA and Plusoptix had the highest sensitivity, surpassing distance VA alone. However, this came at the cost of lower specificity and PPV yet resulting in a higher NPV.

The ROC and AUC analyses of the VA measurement at the screening showed that the VA of the worse-seeing eye had the highest discrimination (AUC > 0.8). At the same time, the IOD only exhibited acceptable discrimination. Stereoacuity and near VA had below-acceptable discrimination (AUC < 0.7). The non-cycloplegic refractions with the Plusoptix indicated that all measurements, except for anisometropia, had acceptable discrimination (AUC 0.7 to 0.8), as illustrated in **Figure 4**.

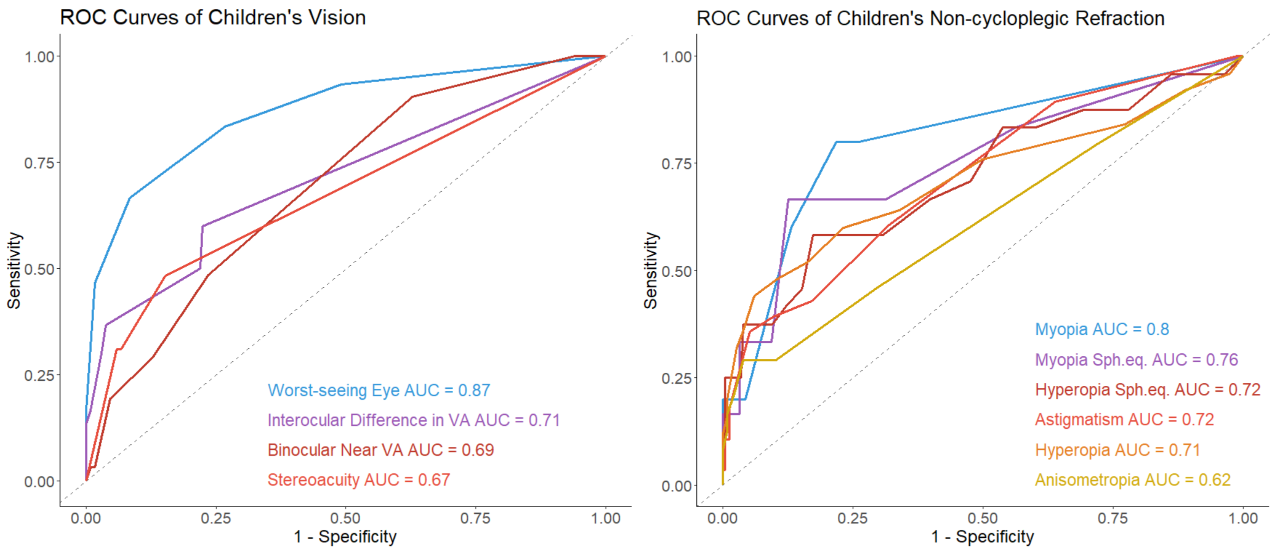

Figure 4: The diagnostic performance of visual acuity and non-cycloplegic refraction measures from the screening was evaluated using Receiver Operating Characteristic (ROC) curves and the corresponding Area Under the Curve (AUC) values. These metrics were used to determine the effectiveness of each measure in identifying the need for referral. An AUC value exceeding 0.8 denotes excellent discrimination, values between 0.7 and 0.8 indicate acceptable discrimination, and values below 0.7 reflect poor discrimination. Analyses cut-offs for refraction are set at Hyperopia (spherical and spherical equivalent) ≥0 diopters (D), Myopia (spherical and spherical equivalent) ≤0 D, Astigmatism ≤0 D, and Anisometropia ≥0 D (III).

Using ROC analysis, the cut-offs for distance VA and refractive errors were determined to achieve the highest sensitivities while maintaining adequate specificities (**Supplementary 2**). These cut-offs were then used to calculate the efficacy of the screening methods, as illustrated in **Table 4a** and **4b**.

Follow-up and clinical findings of participants

In the second study population of six-year-old children (II), 462 children were not referred to an ophthalmologist, and among these, 17 had a distance PVA of 0.3 or more logMAR. Of these, six were already receiving ongoing care from an ophthalmologist or optometrist. Two children underwent new vision screening shortly after that, which turned out normal. Seven of these 17 children were examined by the local ophthalmologist during the follow-up period, resulting in four being prescribed glasses. The last two children who had not been evaluated by an ophthalmologist had a VA of 0.3 in their worse-seeing eyes, with their better-seeing eyes at 0.2 and 0.1, respectively, at the screening. One of these two children had mild hyperopia of +1.0 D, while the other had hyperopia of +2.5 D coupled with astigmatism of -1.5 D, as determined by the Plusoptix device. Both children maintained normal near VA and stereoacuity.

At the screening, an IOD of at least three lines was found in 20 individuals. Five children continued to show an IOD of three or more lines with BCVA throughout the follow-up. Among these, one child was identified with an anomaly of the optic nerve, three were found to have anisometropia with a difference of 3 D or greater, and one child had astigmatism with a value of less than -3.0 D. For the remaining 15 children, the outcomes varied: one child had previous trauma to one eye; 11 children achieved normal BCVA in both eyes; one child maintained a BCVA of 0.2 in both eyes; another child was diagnosed with anisometropia characterised by a 3 D difference and a two-line IOD; and for one child, further information was not available.

Among the four-year-old children (III), 32 required a referral to an ophthalmologist. Of these, 21 were prescribed glasses, and their mean VA in the worse-seeing eye improved from 0.35 to 0.18 logMAR. At the examination following the screening, 11 children had amblyopia with PVA (defined as ≥0.3 logMAR in the worse-seeing eye). However, only five still had amblyopia when assessed with BCVA by the ophthalmologists. Two of these amblyopic children received patch treatment, improving their visual acuities from 1.0 and 0.5 logMAR to 0.4 and 0.3 logMAR, respectively. Vision impairment (defined as ≥0.3 logMAR in the better-seeing eye) was found in six children using PVA, yet only one child remained vision impaired with BCVA. Of the 32 children, 11 were not prescribed glasses after the screening examination but were referred for further assessment within one year. For these 11 children, the mean VA in the worse-seeing eye improved from 0.23 to 0.17 logMAR when examined again. The number of children with amblyopia decreased from four (PVA) to two (BCVA). One of the two remaining amblyopic children was prescribed glasses, and the other was lost to follow-up. None of these 11 children had VI in the better-seeing eye.

During the eye examinations conducted on four-year-old children after the vision screening, several conditions were detected: three were noted to have esophoria, one was identified with esotropia, and 33 children had exophoria. Through slit lamp assessments, ten were found to have a thin strand of persistent pupillary membrane, while one child was found with a coloboma in the iris. Additionally, nine children showed a convergence insufficiency, measuring 10 cm or more from the nose.

Discussion

This thesis provides a detailed analysis of vision screening procedures for children in Greenland. It examines the efficacy of the current vision screening programme for six-year-old school children by assessing the coverage and referral process to an ophthalmologist. Additionally, the prevalence of vision impairment, amblyopia, and refractive errors among six- and four-year-old children in Greenland was investigated. A new screening method for preschool children was also evaluated as part of the overall aim.

Coverage and referral process

Throughout the study period from 2017 to 2022, coverage increased from 43% to 61% for six-year-old children. This rate is much lower than in countries where vision screening of school children is mandatory, with a coverage rate near 100%[74]. It is also lower than in Scandinavian countries, with coverage rates above 95%[68,75]. Only six out of thirteen provinces and territories in Canada have school-based vision screening programmes, and none of the Inuit communities close to Greenland have such programmes[76], making direct comparisons difficult. These differences in coverage illustrate Greenland's challenges due to its vast distances and small population. The lower coverage in Greenland may have multiple explanations. First, not all regional hospitals have permanent school nurses, and the turnover rate of healthcare professionals in Greenland is generally very high. This makes consistent and effective screening programmes challenging to maintain. Second, awareness of the screening programme is not prioritised by the Government of Greenland or the Greenlandic healthcare system. Only a one-page folder with information about health examinations in Greenland is provided to parents shortly after giving birth, and no further information is provided as their child grows. For the past year, regions Avanna, Qeqertalik, and towns in Sermersooq, aside from the capital Nuuk, have had difficulty recruiting school nurses and local doctors. This might explain the low coverage in these regions. Additionally, for the past couple of years, region Kujataa has also started to struggle with the recruitment of these healthcare professionals, which might explain the decline in coverage.

The referral rate to an ophthalmologist after vision screening declined from 14% in 2017 to 5% in 2022, even though the prevalence of vision impairment remained stable. This decline illustrates the inefficiency of the referral process for six-year-old school children. One possible reason for this decline is the absence of paediatric ophthalmologists in Greenland since 2018. As a result, children are now referred to general ophthalmologists from Denmark, but are not being scheduled for examinations, leaving them on waiting lists. Another explanation could be that the current instructions for school nurses regarding the referral process are unclear. The decline in referral rates, combined with follow-up data showing that not all children are referred and that not all referred children are evaluated by an ophthalmologist, poses a risk to the vision health of Greenlandic children.

Conducting register-based studies, as the Coverage Study (I), has challenges[77]. Data are pre-collected by others other than the researchers of this thesis and acquired retrospectively by the researchers. Therefore, the data quality is based on the healthcare professionals who collected the data in the EMR. However, as Greenland only has one EMR system, it is to assume that all entries are recorded in the same EMR, thereby minimising missing data.

Additionally, some children in this thesis are not yet in third grade in public school, so they still have not received the next vision screening by the school nurses. Therefore, this information is not yet available. However, as the coverage is increasing and the prevalence of vision impairment remains relatively stable, it is fair to assume it is representative.

To improve the coverage of the vision screening programme, new referral instructions for school nurses should be implemented, including clear VA cut-offs (≥0.2 logMAR in the worse-seeing eye or ≥2 lines of IOD). Utilising other healthcare professionals, such as optometrists or assistants, could also help enhance coverage. In some countries, schoolteachers are used as screeners with great success[78]. Additionally, information about general health examinations for children and reminder text messages must be made more readily available to parents to increase awareness.

Amblyopia and vision impairment

The prevalence of monocular amblyopia (≥0.3 logMAR) was 2 % for both the six- and four-year-old children (BCVA). This prevalence is lower than those found in Danish children (3.1%)[75] but higher than reported in Canadian children (0.8%)[79], both using the same amblyopia definitions. When defining amblyopia as a VA of ≥0.3 logMAR and ≥2 lines in IOD, the prevalence among six-year-old children decreases from 2% to 1% (BCVA). Hence, care must be taken when comparing the prevalence of amblyopia, as variations in definitions among studies can affect reported prevalence. Using pooled data will most likely minimise the impact of varying definitions. Pooled data from the meta-analysis by Hu et al.[80] indicate that the prevalence of amblyopia is generally higher in Europe compared to North America. The prevalence rates for Greenlandic children in this thesis fall between those observed in these regions. This could be due to variations in healthcare access, vision screening practices, or underlying genetic and environmental factors that influence the development of amblyopia.

The prevalence of vision impairment, defined as a PVA of ≥0.3 logMAR in the better-seeing eye, was 3% for six- and four-year-old children. These rates are comparable to those in the Eastern Mediterranean and the Americas, but lower than those in the Western Pacific (PVA)[63]. Using the WHO criteria for vision impairment (≥0.4 logMAR), the prevalence decreases to 2% for six-year-olds and 1% for four-year-olds. These rates are much lower than those reported (PVA) in the Eastern Mediterranean[81], but similar to the prevalence observed in the USA[82]. These differences suggest that, despite the logistical challenges and limited healthcare resources, Greenlandic children exhibit less severe vision impairment, which may be caused by genetic factors or environmental conditions. Compared to Danish data, which only includes children with a VA of ≥0.6 logMAR, this thesis found a 1% prevalence in six-year-olds and none in four-year-olds. The Danish prevalence is 0.2%[83], but as this thesis uses PVA and the Danish data use BCVA, the prevalence in this thesis might be overestimated.

As this thesis used two different VA charts (HOTV for the six-year-olds and Kay Pictures for the four-year-olds) a direct comparison of prevalence should be cautiously approached. Studies have shown that VA measured with Kay Pictures is better than VA measured with the HOTV chart[84], suggesting that the prevalence of amblyopia and vision impairment among four-year-old children could be underestimated. This could explain why more children had an IOD of two or more lines at the age of six years compared to four years in this thesis.

The presence of amblyopia and vision impairment in Greenlandic children underscores the critical need for ongoing vision screening programmes in Greenland to ensure early detection and intervention. These programmes are vital for preventing long-term vision impairment and supporting the overall health and development of children in Greenland.

Normative data on visual acuity and refractive errors

The mean VA for the better- and worse-seeing eyes was similar across the six- and four-year-old groups. These values are consistent with those observed in children from Scandinavian countries[65,85] and Australia[86]. This suggests that ethnicity does not significantly influence mean VA in children, as demonstrated in a previous study[87].

Overall, both age groups had mild hyperopia (spherical equivalent). Compared to other ethnic groups, Greenlandic children demonstrated more hyperopia than African American and Chinese children but less than White American and Danish children[65,88,89].

The prevalence of cycloplegic myopia (≤-0.5 D) in this study was 4% among six-year-old Greenlandic children and 5% among four-year-olds (6% in SE). These rates are higher than those observed in Danish children, who had no cases of myopia <-0.5 D[65], and higher than the prevalence reported for Swedish children[68] and the indigenous children in Canada[90,91]. As this thesis is based on a cross-sectional design, no causal conclusions can be drawn regarding why Greenlandic children exhibit a higher prevalence of myopia. Not all six-year-old children were measured with a cycloplegic refraction due to the study design, which is why comparisons with the four-year-old children should be made with caution. As a result, the prevalence of myopia among six-year-olds might be underestimated. No previous studies exist in Greenland, making it impossible to compare the historical development of prevalence. Myopia in children and adolescents has received significant global attention recently due to its rising prevalence, particularly in Asian countries. The prevalence is notably higher in urban environments than rural areas, indicating the role of environmental factors[92]. Ethnically, Asian children show a higher prevalence of myopia than their European and African peers[41,92]. These ethnic differences may be largely explained by lifestyle and socio-economic factors rather than genetics[41,93].

The prevalence of hyperopia among six-year-old Greenlandic children was lower than in Danish children[65] and similar to that in Swedish[85]. For four-year-old children, the prevalence of hyperopia was similar to Danish[65] children but higher than Canadian children[91]. The prevalence of astigmatism was higher among the four-year-old group, exceeding that of Scandinavian children[65,85] and more closely resembling Canadian children[91], when using the same cut-off. The higher prevalence of hyperopia among the four-year-olds than the six-year-olds is expected, as emmetropisation typically continues until age six. By setting the cut-off for hyperopia to >+3.0 D, the prevalence decreased to 7% among six-year-old children and 11% among four-year-olds, which is still higher than observed in Newfoundland Canadian children[91]. No other comparable studies from neighbouring Inuit communities could be found.

New screening method

Identifying children with vision impairments during the first vision screening, typically conducted at the age of four, is crucial for timely intervention. In Greenland, where there is no permanent ophthalmologist, and some regions lack healthcare professionals for vision screenings, the sensitivity of the screening method is essential. Children with abnormal screening results may have to wait a year or more to be evaluated by a visiting ophthalmologist, leading to significant delays in proper treatment. Prioritising sensitivity, even if more children are referred for further evaluation, reduces the risk of delayed treatment. Resting children with abnormal results before referral may reduce false positive rates[94]. The new screening method enhanced sensitivity by incorporating near VA, stereoacuity, and non-cycloplegic refraction. The most effective combination was distance VA measurement paired with non-cycloplegic refraction using the Plusoptix device. Given the study design for six-year-old children, including the Plusoptix device is difficult to justify for this age group. The decision to focus on distance VA measurement alone for this age group ensures that the screening process remains practical and effective.

The Government of Greenland recently announced that they would increase the number of school nurses by three to improve service in areas lacking school nurses[95]. This initiative is expected to improve the coverage of vision screening for school children, as the increased number of nurses will allow for more comprehensive and frequent screenings.

In the study of four-year-old children, optometrists successfully conducted the vision screening despite minimal training. Optometrists in Greenland have not previously participated in vision screening of children. This represents a valuable resource that should be further leveraged.

Based on the findings of this thesis, the following recommendations are proposed for a vision screening programme:

<u>Six-year-old children:</u>

- Test:
    - Distance visual acuity using a logMAR chart, i.e. the HOTV chart, which is already used in Greenland.

- Conducted by:
    - School nurses at schools.

Four-year-old children:

- Test:
    - Distance visual acuity using logMAR chart, i.e. Kay Pictures. Lea Symbols or HOTV.
    - Non-cycloplegic refraction using Plusoptix.
- Conducted by:
    - Optometrists at kindergartens.

Referral criteria:

- Visual acuity of ≥0.2 logMAR or an interocular difference of ≥2 lines for both age groups.
- Plusoptix for the four-year-old children:
    - Hyperopia >+2.0 D
    - Myopia ≤-0.5 D
    - Astigmatism: ≤-1.0 D
    - Anisometropia: ≥1 D

New referral pathways should be implemented. School nurses will submit a list of children to a regional secretary within the healthcare system, who will then refer the children to an ophthalmologist. Optometrists in Greenland already refer children directly to an ophthalmologist.

Collaboration with the Greenlandic Healthcare System and possibly the Greenlandic Government is essential to implement this new screening method and referral pathway. Efforts to initiate this process have already begun.

Better coverage of the vision screening programme also involves raising awareness among parents and caregivers in kindergartens and schools about the importance of early vision screening. A new national campaign launched in Greenland in 2022 specifically addressed this issue[96]. Additionally, sending reminder texts to parents about health examinations at the hospital when their child turns four could help increase participation and ensure more children are included.

Implementing this new screening method ensures that Junkers Principles for mass screening are still fulfilled, emphasising accessible, efficient, and high-quality health assessments. However, introducing new screeners and a new device changes the cost structure of the screening programme. The estimated cost for having optometrists conduct the screenings is based on their ability to screen one child every five minutes and the inclusion of five optometry stores in Ilulissat, Sisimiut, and Nuuk. There are approximately 800 children born each year in Greenland. Screening all of them, each child taking 5 minutes, would take at least ten days of continuous screening. However, given that Greenland has 17 towns, a minimum of 17 days is required to cover each location. The time required varies by town size: larger towns need more than a day to complete the screenings—Nuuk requires at least four days, while Ilulissat, Qaqortoq, and Sisimiut each require at least two days. The remaining towns can be completed in one day each. The cost of 79 DKK to screen one four-year-old child at the kindergarten is not higher than the cost of vision screening in other countries[74,97], which is considered acceptable. This cost is based on a best-case scenario of 24 days. For a worst-case scenario, adding 25% more days (i.e., 30 days in total), the cost will be 98 DKK per child (see **Supplementary III**). For comparison, a health examination at a local doctor in Denmark, which includes vision screening, costs 229 DKK[98]. A more thorough cost-effectiveness analysis should be conducted in the future if the new screening method is implemented. Additionally, an analysis of the rate of false positives should be conducted to determine if it can be further reduced with different cutoffs.

These suggestions can serve as a basis for decision-makers in Greenland to enhance the effectiveness of screening for Greenlandic children.

Conclusion

This thesis evaluated the efficacy and coverage of the vision screening programme for schoolchildren in Greenland, examined the prevalence of vision impairment and refractive errors among Greenlandic school and preschool children, and assessed a new screening method for preschool children conducted by professionals in Greenland who were new to vision screening.
The findings confirm that the current coverage, although increasing, remains insufficient compared to Scandinavian countries, necessitating further expansion. Greenland is the only country with a school-based vision screening programme compared to its neighbouring Inuit Communities in Canada.
The existing screening programme does not adequately identify all children requiring an ophthalmological evaluation. Children with potential vision issues are not consistently referred for further assessment, highlighting a critical gap in early detection and intervention. The referral pathways need significant enhancement to ensure timely and appropriate follow-up care for these children.
Greenlandic children generally exhibit good visual acuity. However, the prevalence of amblyopia and vision impairment is significant, underscoring the need for continuous vision screening to identify and support children in need of treatment. The study also found a higher prevalence myopia among Greenlandic children compared to their peers in Denmark and Canada/USA. The prevalence of hyperopia among six-year-old Greenlandic children was lower than in Danish children and similar to that in Swedish children. Among four-year-olds, hyperopia prevalence was similar to Danish but higher than Canadian children, while astigmatism prevalence was higher than in Scandinavian and more similar to Canadian children.
To enhance the screening programme, the inclusion of non-cycloplegic refraction using a photoscreener is recommended, as it would improve detection accuracy by increasing sensitivity.
Overall, while the current vision screening programme has made progress, significant improvements are needed to fully address the visual health needs of Greenlandic children. Enhanced screening coverage, improved referral processes, and better screening techniques are crucial to ensure early detection and intervention for vision impairments.
The inclusion of new screening methods and the involvement of optometrists demonstrate the feasibility and effectiveness of these approaches, contributing to advancements in vision screening practices. Although this approach may increase initial costs, it is expected to become

more cost-effective after the first year. These findings provide a basis to help decision-makers in Greenland improve vision screening for Greenlandic children, potentially leading to better vision health outcomes.

Future perspectives

The findings of this thesis provide a foundation for several important areas of future research and development in the field of vision health for Greenlandic children. These future perspectives not only build on the current work but also aim to address gaps and explore new opportunities for enhancing vision care in Greenland.

The proposed new vision screening method, which includes non-cycloplegic refraction using a photoscreener, represents a significant advancement over the existing programme. However, future studies should critically assess its effectiveness. Key areas of focus should include the accuracy of detecting refractive errors and amblyopia, the practicality of implementation in diverse geographical and socioeconomic contexts, and the overall cost-effectiveness of the method.

Vision impairment and amblyopia can significantly impact the quality of life of affected children, influencing their academic performance, social interactions, and overall well-being. A dedicated study exploring the quality of life among Greenlandic children with these conditions would provide valuable insights. This research could assess the psychosocial and educational challenges faced by these children and evaluate the long-term benefits of early diagnosis and treatment. Understanding these aspects can help tailor support services and educational programmes to meet the needs of these children better, enhancing their overall life experience. As of today, the previous collaboration with Danish low vision specialists, who provided essential support and expertise, has been terminated. Reinstating this collaboration would be highly beneficial, ensuring that children with vision impairments receive the specialised care and resources they need for optimal development and quality of life.

The development of myopia in Greenlandic children and adolescents is an area warranting further investigation, particularly regarding its genetic and environmental determinants. Future research should aim to identify the prevalence and progression of myopia, comparing these trends with other populations. Genetic studies could explore the hereditary factors contributing to myopia and thereby enable the possibility of identifying children at risk of high myopia through genetic testing. This would ensure early treatment with specialised contact lenses or glasses designed to slow the progression of myopia, ultimately helping to prevent the development of high myopia in adulthood[99,100].

Advancements in technology offer promising solutions to reduce the waiting time for ophthalmological care and improve the delivery of vision services in Greenland. Integrating technologies such as smartphone-based visual acuity testing, portable autorefractors, and ready-made glasses can significantly enhance access to vision care[101–103]. For example, optometrists or other healthcare professionals in rural areas of Greenland could use transportable fundus photography and tonometers to detect conditions that might otherwise require evaluation by an ophthalmologist. These innovations may enable quicker diagnosis and treatment, ensuring children receive the necessary care promptly. Furthermore, expanding the scope of practice for Greenlandic optometrists to include the administration of cycloplegic eye drops for accurate refraction measurements could improve the quality of vision care. In remote areas lacking optometrists or ophthalmologists, telemedicine, combined with the abovementioned technologies, could provide an effective solution. This approach would facilitate the rapid provision of glasses and other vision aids, ensuring children across Greenland receive timely and equitable vision care.

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Appendix: Papers I, II, and III

Paper I

VISION SCREENING OF SCHOOL CHILDREN IN GREENLAND 2017-2022: COVERAGE AND LOW VISION PREVALENCE

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ABSTRACT

Vision screening during childhood is vital for the early detection and treatment of visual impairment that may significantly impact a child's development and quality of life. This nationwide cross-sectional study used data from Greenland's national electronic medical records, including 2,493 six-year-old children from July 2017 to July 2023, to evaluate the coverage rate of vision screening and the prevalence of low vision in Greenlandic schoolchildren. The participation rate in vision screening increased from 43% in 2017 to 61% in 2022, while referral rates to ophthalmologists decreased from 14% in 2017 to 5% in 2022. The mean prevalence of impaired vision (≤0.50 Snellen decimal) in the better-seeing eye at the vision screening throughout the study period was 3%. At the same time, it was 8% for the worse-seeing eyes, indicating a continuous need for ophthalmological evaluation of the Greenlandic children. Notably, referral rates to ophthalmologists decreased from 14% in 2017 to 5% in 2022 without a corresponding decrease in the prevalence of low vision. This study highlights healthcare delivery challenges in Greenland's sparsely populated areas and emphasises the need for new national guidelines to optimise referral processes. Utilising other healthcare professionals, such as optometrists, for vision screenings and ensuring follow-ups are critical for improving the visual health outcomes of Greenlandic children.

Keywords

Arctic, Greenland, School Children, Vision Screening, Visual Acuity

INTRODUCTION

Early detection and treatment of visual impairment is essential to avoid negative impacts on children's development and quality of life. The World Health Organization (WHO) strongly recommends routine vision screenings to prevent and reduce the global burden of eye diseases, which may lead to severe vision loss or blindness if left untreated[1]. Early detection of reduced visual acuity in children vastly improves educational outcomes, social engagement, and overall well-being[2–4].

Greenland has adapted its healthcare system to its vast and sparsely populated areas by dividing them into five health regions. A regional hospital centres each region, while the capital hosts the national hospital, providing specialised care for all regions. However, there is no permanent ophthalmologist based in Greenland. Instead, visiting consultants from Denmark deliver annual examinations to each town. Between these visits, most ophthalmological assessments are conducted via telemedicine in nine of the sixteen towns, emphasising the reliance on remote healthcare solutions.

Greenland has implemented multiple screening programs targeting various health issues, such as hearing ability in children, gestational diabetes, diabetic eye disease, mammography, and cervical cancer. Despite these efforts, coverage rates for many of these programs are notably low, reflecting the logistical and infrastructural challenges of the healthcare system[5–7]. The diabetic eye disease screening program is among the most successful screening programs[8].

The vision screening program, conducted by school nurses, is critical to supporting children with developmental needs. In the current vision screening program, school nurses advise children to consult their local doctor or an optometrist if the visual acuity in their worse-seeing eye measures 0.63 Snellen decimal or worse. However, the absence of permanent school nurses in some regions further reduces the effectiveness of these screenings.

Hence, the present study aims to evaluate the coverage rate of vision screening in schoolchildren in Greenland, identify the prevalence of low vision within this population, and assess the subsequent follow-up actions for those with visual impairments.

METHODS

Design

A nationwide register study was conducted using data from Greenland's national electronic medical records (EMR).

Study population and data extraction

All residents of Greenland have a unique personal registration number (CPR), with the first six digits representing the date of birth. Using this, we extracted data from the EMR of all six-year-old children from July 2015 to July 2023. The data extraction took place in December 2023. The study extracted only medical records with a specific entry of a general health examination from the school nurse in the first grade of primary school. From these entries, we recorded visual acuity (VA) measurements of each eye, place of screening, and birthdate. If the VA was ≤0.63 Snellen decimal in either eye, we recorded information about any ophthalmological examinations, treatments, and future vision screenings.

Screening results were divided into school years from July 2 to July 1 of the following year. The towns and settlements were grouped into Greenland's five regions (**Figure 1**).

This study followed the Declaration of Helsinki and was approved by the Greenland Science Ethics Committee (ID-number 2023-20891) and the Greenlandic Health Service.

Definitions

The referral cutoff for vision impairment in Greenland is a VA of ≤0.63 Snellen decimal in the worse-seeing eye. In this paper, varying cutoffs of vision impairment in both the worse- and better-seeing eyes, including VA as low as 0.25 Snellen decimal, are used to provide a basis for comparing our findings with international data. Notably, a VA of <0.3 Snellen decimal is considered significant vision impairment in the Scandinavian countries and Greenland[9–11].

Statistics

The measurements were presented as VA of the right and left eye and as the worse- and better-seeing eye.

Data were collected using a logMAR visual acuity chart and recorded as logMAR values. The mean and standard deviation (SD) of these values were calculated and then converted to Snellen decimals using the formula: Snellen decimal = $10^{-\text{logMAR}}$. The range for Snellen decimals was calculated by converting the mean logMAR +/- the SD to Snellen decimals. The normally distributed measurements were presented as means with range. The participation rates, visual acuity, and interocular differences in VA were calculated and presented as percentages with 95% confidence intervals (CI), computed using the normal approximation (**Table 1**).

Data from Statistics Greenland was used to calculate annual participation rates[12].

RESULTS

We included 2493 children with a mean age of 6.44 years (SD: 0.36 years, range 5.01 – 7.76 years).

The participation rate showed an upward trend, starting at 43% [95% CI: 42%, 43%] in 2017 and increasing to 61% [95% CI: 61%, 62%] in 2022. (**Table 1**).

The mean VA for the right and the left eye across all years was 0.91 (Range: 0.69 – 1.20); for the worse-seeing eye, the mean VA was 0.87 (Range: 0.63 – 1.20); and for the better-seeing eye, it was 0.93 (Range: 0.74 – 1.17), as shown in **Table 1**.

Overall, 9% [95% CI: 8%, 10%] of the participants had a VA of ≤0.63 (Snellen decimal) in the better-seeing eye, and 16% [95% CI: 14%, 17%] in the worse-seeing eye. These proportions decreased with stricter VA thresholds, down to 1% [95% CI: 0%, 1%] for VA ≤0.25 (Snellen decimal) in the better-seeing eye and 2% [95% CI: 1%, 3%] in the worse-seeing eye. The interocular difference of ≥2 lines of VA remained stable at an average of 6% [95% CI: 5%, 7%] (**Table 1**).

Overall, the proportion of children with poor visual acuity decreased with the severity of vision loss in the study period (**Figure 2**).

The annual proportion of children seen by an ophthalmologist decreased throughout the study period, from 14% [95% CI: 10%, 17%] in 2017 to 5% [95% CI: 3%, 7%] in 2022. This trend paralleled the proportion of children having prescribed glasses, which was 8% [95% CI: 5%, 11%] in 2017 and reduced to 4% [95% CI: 2%, 5%] in 2022 (**Figure 3**).

The participation rate has increased over the years, reflecting greater inclusion of children across various regions. The participation rate was consistently low in the regions of Avanna Qeqertalik and Sermersooq (**Figure 4**).

Of the 389 children with impaired VA of ≤0.63 Snellen decimal, 57% (n=221) were not referred to an ophthalmologist. Among these, 78% (n=172) lacked records of further vision screening. Out of the 168 children who were referred to an ophthalmologist, 114 were prescribed glasses. Among the 54 children who were not prescribed glasses, 12 had a Best Corrected Visual Acuity (BCVA) of ≤0.50 (Snellen decimal) on one or both eyes. The ophthalmological findings of these 12 children were as follows: Two had optic nerve anomalies, one was concluded to have a non-organic ophthalmological cause, and two children were prescribed glasses years later by an optometrist. Four children were discharged without treatment, maintaining a BCVA around 0.5-0.63 (Snellen decimal). Three children had permanent amblyopia in one or both eyes, with one case caused by corneal scarring in one eye. Only one of the three children with amblyopia underwent patch treatment, which was unsuccessful (**Figures 5** and **6**).

DISCUSSION

The present study provides a comprehensive overview of vision screening among children in Greenland. The participation rates have shown an upward trend from 43% in 2017 to 61% in 2022. The additional training received by school nurses in 2017 and more efficient utilisation of medical records may contribute to this increase. Greenland's neighbouring Inuit communities in Canada have no school-based vision screening programs for comparison[13]. However, the participation rates in Greenland are still lower than in the rest of Europe and the USA, which have more centralised healthcare systems[14–17]. Such differences underline the challenges Greenland's vast and sparsely populated rural areas pose, and how this complicates healthcare delivery. Nevertheless, the increasing trend in participation is a positive sign, indicating gradual improvements in health service outreach and engagement.

In our study, 3% of children showed impaired vision (≤0.50 Snellen decimal) with presenting visual acuity (PVA) in the better-seeing eye. This finding was reasonably consistent throughout the study period, with the proportion of children with impaired vision ranging from 2% to 5%. This rate is similar to the Americas, yet lower than in Southeast Asia, Africa, and the Eastern Mediterranean[18]. These differences in the rates suggest regional differences in health outcomes, possibly due to variations in healthcare access and policies. A more conservative criterion of ≤0.32 Snellen decimal reduced the prevalence of impaired vision to 1% in the better-seeing eye. This lower prevalence is similar to the Eastern Mediterranean and lower than in European populations[18], indicating possibly less severe visual impairment in Greenlandic children despite healthcare delivery challenges.

Conversely, the prevalence of visual impairment (≤0.50 Snellen decimal) in the worse-seeing eye was 8%, and an interocular difference of ≥2 lines was 6%. These rates are significantly higher than the 3.1% and 4.7%, respectively, observed in Danish children[19], reflecting possible differences in healthcare access or the effectiveness of early intervention programs. Using WHO's criterion of ≤0.40 Snellen decimal in the better-seeing eye[20], our prevalence of visual impairment was 2%, allowing for direct comparison with global standards and underscoring the need for targeted vision health strategies in Greenland. However, using register data introduces a risk of missing or incomplete data, possibly leading to an underestimation of vision impairment.

A concerning trend from our study is the decreasing rate of children with poor VA seen by ophthalmologists, which dropped from 14% in 2017 to only 5% in 2022. Despite this decrease, the proportion of children with poor VA remains high, with 16% of children having a VA of ≤0.63 Snellen decimal in the worse-seeing eye and 8% a VA of ≤0.50 Snellen decimal, indicating a substantial number of children needing ophthalmological care. This decline in visits to an ophthalmologist indicates inefficiencies in the referral process and could significantly impact child health due to the importance of early detection and intervention. Another possible explanation is that since 2017, no pediatric ophthalmologists have visited Greenland. The Greenlandic Healthcare System now relies solely on general ophthalmologists, rather than pediatric specialists.

In regions lacking school nurses, utilising other healthcare professionals, such as optometrists, may be beneficial in conducting vision screening. In addition, the consistently high proportion of children with low vision in their worse-seeing eyes indicates that preschool vision screening might be ineffective and needs evaluation.

New national guidelines outlining referral criteria for school nurses are required to optimise the referral process. Appointing regional personnel to ensure follow-ups for referred children will most likely minimise the shortfalls in consultations by ophthalmologists.

In conclusion, although the participation rate has increased from 2017 to 2022, the referral rate to an ophthalmologist has decreased in the same timeframe without a corresponding decrease in the proportion of low vision. Low vision in Greenlandic schoolchildren exists and remains a critical concern. Utilising other healthcare professionals, such as optometrists, for vision screening in regions without school nurses, along with streamlined referral processes, is essential for improving visual health outcomes for Greenlandic children.

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Data Acquisition/Research Execution: ND.

Data Analysis/Interpretation: ND, IF, IN, HJ.

Manuscript Preparation: Original Draft: ND, IN, HJ Writing, Review & Editing: ND, IN, IF, MEJ, SH, HJ.

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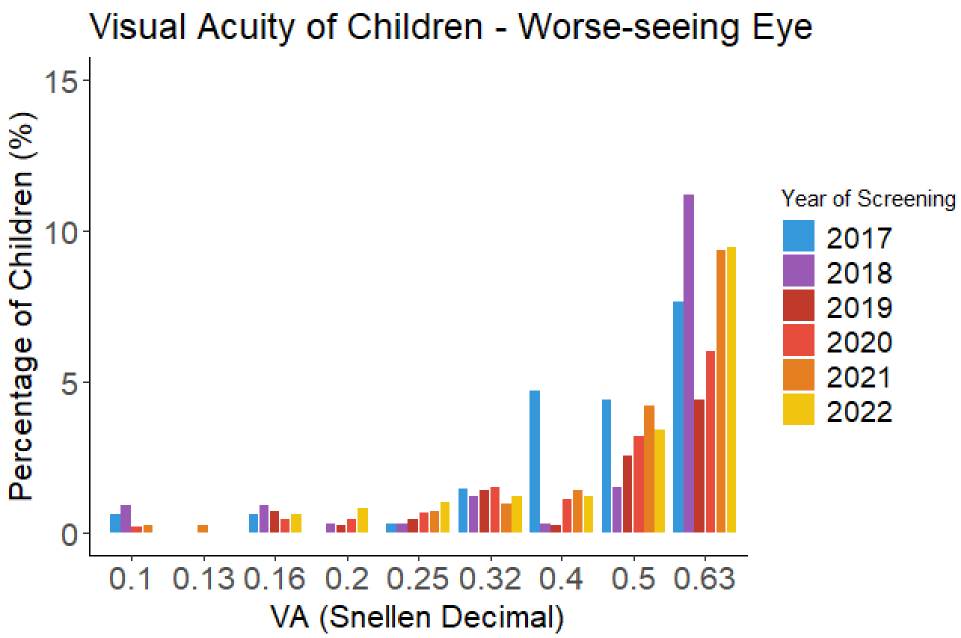
Table 1: Characteristics of Participating Greenlandic Children at the Vision Screening at the Age of Six Years Between 2017 and 2022

Characteristic	2017 n=341	2018 n=330	2019 n=430	2020 n=466	2021 n=435	2022 n=491	All Years n=2493
Age at Screening (years) [1]	6.45 ± 0.33	6.54 ± 0.32	6.41 ± 0.30	6.48 ± 0.31	6.41 ± 0.41	6.37 ± 0.41	6.44 ± 0.36*
VA Right Eye (Snellen decimal) [1]	0.89 (0.67 – 1.18)	0.91 (0.69 – 1.20)	0.93 (0.72 – 1.20)	0.91 (0.69 – 1.20)	0.89 (0.68 – 1.17)	0.87 (0.66 – 1.15)	0.91 (0.69 – 1.20)
VA Left Eye (Snellen decimal) [1]	0.87 (0.62 – 1.23)	0.91 (0.68 – 1.23)	0.93 (0.74 – 1.17)	0.93 (0.71 – 1.23)	0.91 (0.69 – 1.20)	0.89 (0.66 – 1.20)	0.91 (0.69 – 1.20)
Worse-seeing Eye (Snellen decimal) [1]	0.83 (0.58 – 1.20)	0.87 (0.60 – 1.26)	0.91 (0.69 – 1.20)	0.89 (0.65 – 1.23)	0.87 (0.65 – 1.17)	0.85 (0.62 – 1.17)	0.87 (0.63 – 1.20)
Better-seeing Eye (Snellen decimal) [1]	0.93 (0.74 – 1.17)	0.95 (0.79 – 1.15)	0.95 (0.78 – 1.17)	0.95 (0.76 – 1.20)	0.93 (0.72 – 1.20)	0.91 (0.72 – 1.15)	0.93 (0.74 – 1.17)
Participation rate (%)¥	43 [42,43]	43 [43,44]	59 [58,59]	60 [59,60]	57 [56,57]	61 [61,62]	54 [53.5,53.8]
Prop. VA≤0.63† Better-seeing eye (%)	9 [6, 12]	10 [7, 13]	5 [3, 7]	6 [4, 9]	12 [9, 15]	11 [8, 14]	9 [8, 10]
Prop. VA≤0.63† Worse-seeing eye (%)	20 [15,24]	17 [13,21]	10 [7,13]	14 [10,17]	17 [14,21]	18 [14,21]	16 [14,17]
Prop. VA≤0.50† Better-seeing eye (%)	5 [2, 7]	2 [0, 3]	2 [1, 3]	3 [2, 5]	3 [1, 5]	4 [2, 6]	3 [2, 4]
Prop. VA≤0.50† Worse-seeing eye (%)	12 [9,16]	5 [3,8]	6 [3,8]	8 [5,10]	8 [5,10]	8 [6,11]	8 [7,9]
Prop. VA≤0.40† Better-seeing eye (%)	1 [0, 2]	1 [0, 1]	2 [1, 3]	2 [1, 3]	1 [0, 3]	2 [1, 3]	2 [1, 2]
Prop. VA≤0.40† Worse-seeing eye (%)	8 [5,10]	4 [2,6]	3 [1,5]	4 [2,6]	4 [2,5]	5 [3,7]	4 [4,5]

Characteristic	2017 n=341	2018 n=330	2019 n=430	2020 n=466	2021 n=435	2022 n=491	All Years n=2493
Prop. VA≤0.32† Better-seeing eye (%)	0 [0,0]	1 [0,1]	1 [0,3]	2 [0,3]	1 [0,2]	1 [0,2]	1 [0,1]
Prop. VA≤0.32† Worse-seeing eye (%)	3 [1,5]	4 [2,6]	3 [1,4]	3 [2,5]	2 [1,3]	4 [2,5]	3 [3,4]
Prop. VA≤0.25† Better-seeing eye (%)	0	0 [0,1]	1 [0,1]	1 [0,1]	1 [0,2]	1 [0,2]	1 [0,1]
Prop. VA≤0.25† Worse-seeing eye (%)	1 [0,3]	2 [1,4]	1 [0,3]	2 [1,3]	1 [0,2]	2 [1,4]	2 [1,3]
Prop. ≥2 interoc. diff.‡(%)	8 [5,10]	7 [4,9]	4 [2,6]	6 [4,8]	5 [3,8]	5 [3,7]	6 [5,7]

VA = Visual Acuity (Snellen decimal) as a presenting visual acuity (PVA)
[1] Mean with range (lower – upper limit, based on SD of logMAR values)
*Age range: 5.01 – 7.76 years
¥ Participation rate with [95% Confidence Interval]
†Proportion with specific VA's (Snellen decimal) in percent with [95% Confidence Interval]
‡Proportion with an interocular difference of ≥2 lines in percent with [95% Confidence Interval]

Figure 1: Map of Greenland illustrating the five regions.



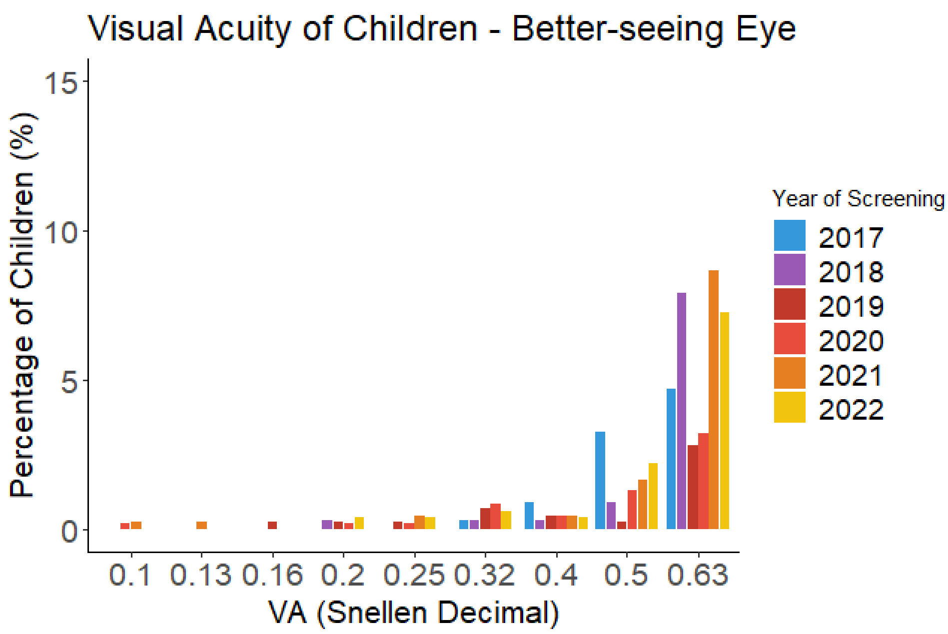


Figure 2: Proportion of children with visual acuity (VA) of 0.63 (Snellen decimal) or worse for the years 2017-2022. A different colour represents each year. The figure on the left shows the worse-seeing eyes, and the figure on the right shows the better-seeing eyes.

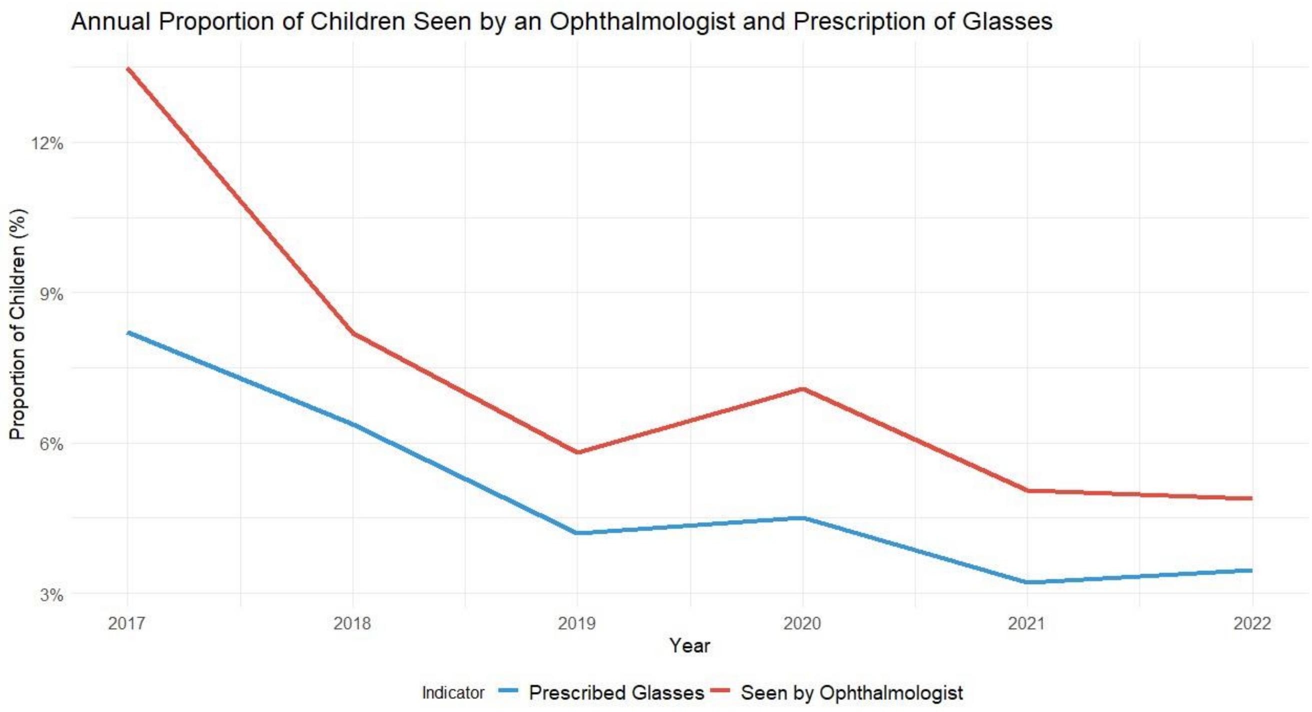


Figure 3: Proportion of children prescribed glasses (blue line) and seen by an ophthalmologist (red line) for the years 2017-2022. An ophthalmologist saw fever children in 2022 and prescribed fever glasses in 2022.

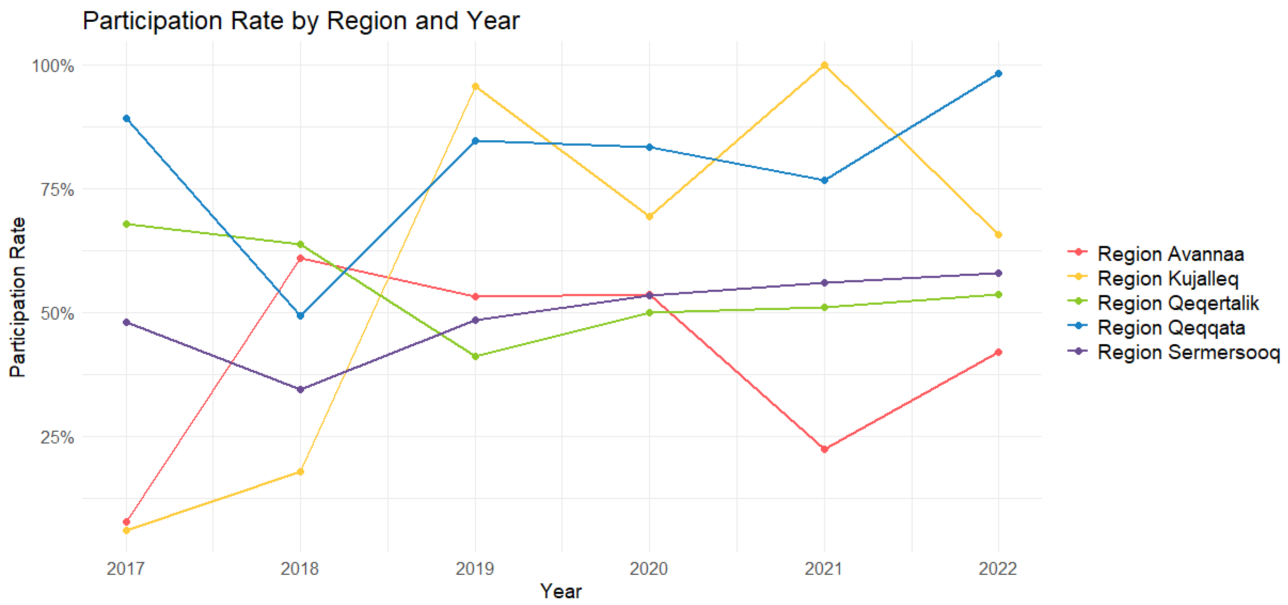


Figure 4: Participation rates for each region from 2017 to 2022, illustrating the fluctuating participation trends over the years.

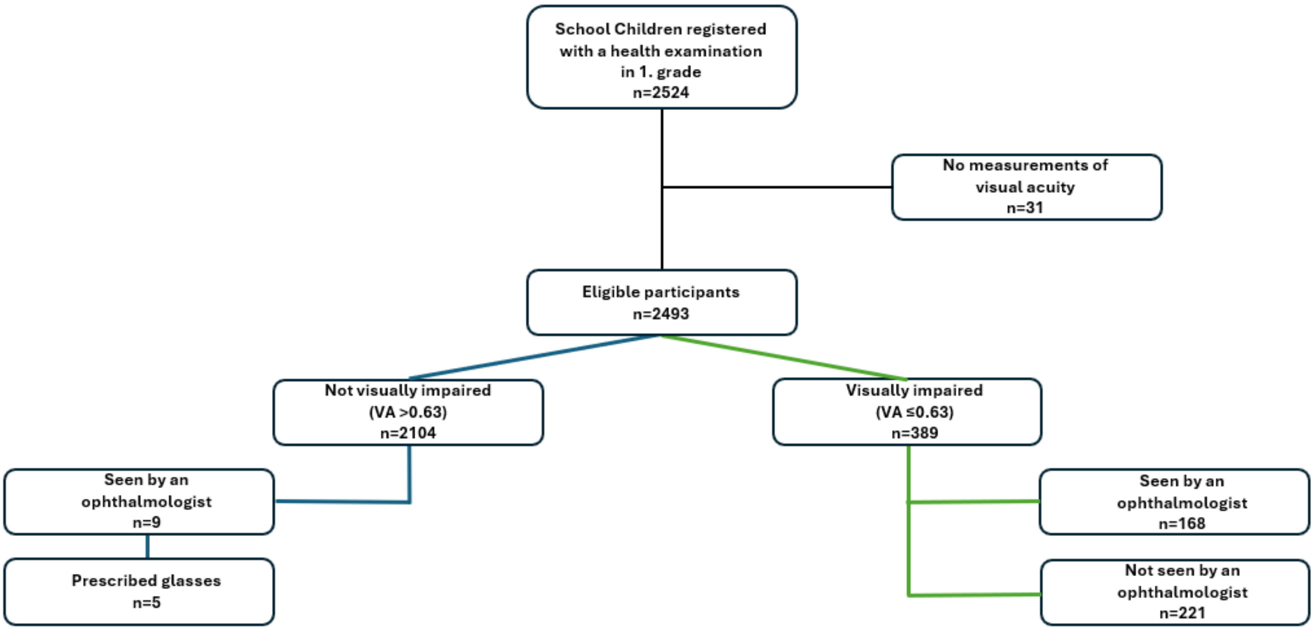


Figure 5: Flowchart of the participants.

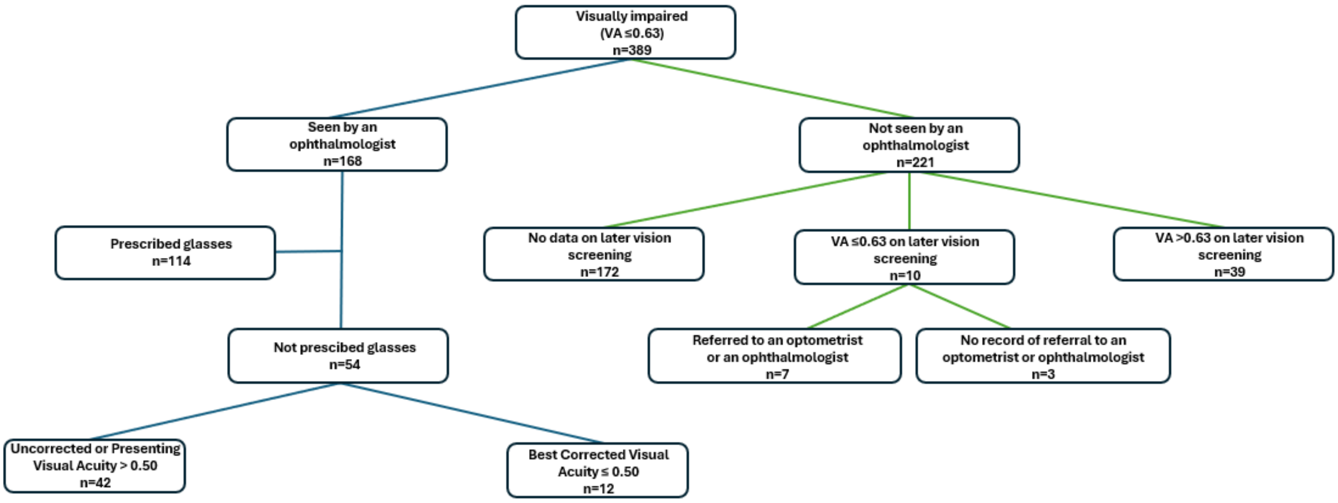


Figure 6: Flowchart showing children with impaired vision (≤0.63 Snellen decimal), divided by a visit to an ophthalmologist. The chart also details the outcome for referred children and additional available information obtained for those not referred.

Paper II

VISION SCREENING AND REFRACTION OF GREENLANDIC SCHOOLCHILDREN

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ABSTRACT

Purpose: To estimate the prevalence of amblyopia and refractive errors among six-year-old children in Greenland and to assess the impact of incorporating autorefraction, stereoacuity and near visual acuity testing into vision screening.

Methods: In this cross-sectional study, 517 children (238 girls and 279 boys) from 21 locations in Greenland were screened using HOTV charts for distance and near visual acuity (VA), stereoacuity test, and non-cycloplegic autorefraction. Referral criteria for further ophthalmological examination included a VA of ≥0.2 logMAR on the worse-seeing eye or an interocular VA difference of ≥2 lines.

Results: Initial screening identified amblyopia (defined as VA of ≥0.3 logMAR) in 7% (unilateral) and 3% (bilateral) of children. However, subsequent ophthalmological examinations confirmed amblyopia in under 40% of referrals. Significant interocular VA differences were found in 9%. The prevalence of refractive errors at the screening was 3% for myopia (≤-0.5 dioptres), 10% for hyperopia (>+2.0 dioptres), and 14% for astigmatism (≤-1.00 dioptres), while the corresponding prevalences at the ophthalmological examination were 4% for myopia, 8% for hyperopia, and 6% for astigmatism. Combining screening measurements increased the positive predictive values, thereby enhancing screening accuracy. Specifically, the incorporation of autorefraction or stereoacuity with distance VA demonstrated to be the most effective combination. Six percent of the children were prescribed glasses after the screening procedure.

Conclusion: This study provides the first visual profile of Greenlandic schoolchildren. Incorporating autorefraction, stereoacuity, and near visual acuity in vision screenings enhanced the efficacy of detection of vision anomalies. Although this may lead to more false positives, accurate screening is crucial in regions with limited ophthalmological resources.

Keywords: Amblyopia, Arctic, Child, Refraction, Screening, Visual acuity

INTRODUCTION

The primary purpose of vision screening is the early detection of children with strabismus and refractive errors, which both increase the risk of amblyopia (WHO, 2019), with the latter being one of the most common causes of visual impairment globally (Flaxman et al., 2017).

In Greenland, vision screening for schoolchildren is recommended at the age of six years by a school nurse, following the Danish guidelines (Government of Greenland, 2005; Danish Health Authority, 2019). While high participation rates for vision screening have been reported in Scandinavia (Bro & Löfgren, 2023; Falkenberg et al., 2019; Høeg et al., 2015), the participation rate in Greenland remains unknown. Although the first vision screening for children in Greenland is recommended at the age of four, the participation rate at this initial stage remains unknown. However, the coverage rate of the Measles, Mumps, and Rubella vaccine, administered during the 4-year health examination where vision screening is also performed, is as low as 40% in the districts (Albertsen et al., 2020). This suggests that the coverage for preschool vision screening is likely similarly low. The current referral criterium is distance visual acuity of ≥0.2 logMAR. Moreover, Greenland does not have a permanent ophthalmologist, relying on annual visits from Danish consultants to its 17 cities. Most ophthalmological examinations in Greenland are conducted via telemedicine, available in only nine cities across Greenland. Ophthalmological patients must be transported to the nearest city with equipment for the examination. Additionally, seven out of 17 cities in Greenland lack school nurses, further limiting the availability of ophthalmological examinations.

Greenland's population consists of 56,000 inhabitants where >80% are Inuit (Statistics Greenland, 2024). The healthcare system is divided into five regions, each with a regional hospital; additionally, the Capital hosts the national hospital. All specialised care is available in the Capital. The regional hospitals operate primarily in a primary care setting.

The current vision screening method in Greenland is performed using the Østerberg picture chart (Osterberg, 1965), which has several limitations. These include a lack of equidistant size difference between lines with increasing number of figures and increasing distance between figures with increasing visual acuity demand. Hence, the crowding phenomena vary as the figures change size (Kaiser, 2009), and comparison with logMAR visual acuity charts indicates an underestimation of visual acuity, especially among patients with low vision (Yu et al., 2021), and inferior test-retest accuracy (Lovie-Kitchin, 2015).

The introduction of preschool vision screening based on distance visual acuity is an important tool in reducing the prevalence of amblyopia (Høeg et al., 2015; Thorisdottir et al., 2019), but significant hyperopia, anisometropia, and astigmatism may go undetected, suggesting that a more sensitive vision screening is required.

Visual impairment in children with amblyopia has multiple negative impacts on their daily activities. Amblyopic children exhibit a 25% slower reading speed compared to children without visual impairment, a deficit that persists even when the amblyopic eye is occluded (Kelly et al., 2023). Children successfully treated for strabismus, either with optical correction or surgery, no longer show reduced reading speed (Kelly et al., 2015). Additionally, amblyopic children demonstrate impaired motor function with reduced balance and manual dexterity (Birch et al., 2023; Brin et al., 2022). The quality of life is frequently reduced in children with residual amblyopia compared to non-amblyopic children with glasses (Hatt et al., 2020), further stressing the need for early detection of visual impairment.

The prevalence of amblyopia and refractive errors among Inuit populations in Greenland and other circumpolar countries has not been studied in recent years. However, one recent study found that 5.9% of the children aged 0-9 years were at risk of developing amblyopia in Nunavik, Canada (Tousignant & Brûlé, 2022).

Hence, the aim of this study was to estimate the prevalence of amblyopia and refractive errors and to assess whether adding autorefraction and stereoacuity testing to the screening procedures will reduce the number of undetected vision anomalies among six-year-old children in Greenland.

MATERIAL AND METHODS

Design

A population-based cross-sectional study covering 13 cities and 10 settlements in Greenland. The three northernmost cities and one on the east coast were not included due to the lack of school nurses. Three cities in South Greenland without school nurses were included, as the dispatch of a school nurse from the Capital made it possible to conduct the vision screenings. The study was conducted between September 2017 and October 2018. The study followed the Tenets of the Declaration of Helsinki and was approved by the Greenlandic Science Ethics Committee (ID-number 2023-15841) and the Greenlandic Health Service. In 2017, the standard vision screening protocol, which is part of the regular health examination for school children and previously consisted of visual acuity measurement for distance, was expanded to include three additional tests: autorefraction, near vision testing, and stereoacuity testing.

Participants

All first-grade primary schoolchildren in participating cities and settlements in Greenland, aged six years (range 5.0 – 7.4 years), were invited to participate in this study.

Screening procedures

Prior to screening, the school nurses attended a two-day training course with theoretical lectures and supervised clinical training by a paediatric ophthalmologist to ensure procedural uniformity. Subsequently, all necessary equipment was provided.

The screening procedure consisted of:

- Distance visual acuity (VA) was measured monocularly at 3-meter distance with uncrowded letter presentation of a HOTV test chart (Cat. No. 2014) with five optotypes (H, O, T, or V) on each line. An eye patch covered the non-examined eye, and the test was repeated under binocular viewing conditions.
- Near VA was measured at 40 centimetres binocularly with a crowded near HOTV test chart (Cat. No. 2017).
- Stereoacuity was measured at 40 centimetres with Lang II Test.
- Non-cycloplegic autorefraction was measured using Plusoptix A12R (Plusoptix GmbH, Nuremberg, Germany).
- Ongoing outpatient contact with an ophthalmologist or optometrist was recorded, and optical correction prescribed and/or worn during screening.
- Additional observations about the vision or eye anomalies, including strabismus, were recorded.

During screening, the children wore their habitual glasses. All results were sent to a paediatric ophthalmologist. Referral to a local ophthalmologist for a full eye and vision examination was recommended if distance Presenting Visual Acuity (PVA) was equal to or higher than 0.2 logMAR (≤6/9.5 Snellen fraction) or a difference of monocular VA of ≥2 lines between the right and the left eye. The ophthalmological examinations potentially included distance Best Corrected Visual Acuity (BCVA), a slit lamp examination, Hirschberg test for strabismus, and a cover test for manifest and latent strabismus, as well as cycloplegic autorefraction and ophthalmoscopy. In Greenland, a cycloplegic refraction is performed using 1% Cyclopentolate, instilled at least twice at 10-minute intervals. Autorefraction is measured at least 30 minutes after the last drop. However, it is important to note that we had no influence on the ophthalmological examination conducted by the ophthalmologist as the child was referred to the standard healthcare system in Greenland. Glasses were prescribed based on an individual evaluation.

Definitions

Amblyopia was defined as visual acuity of 0.3 logMAR (6/12 Snellen fraction) or poorer in one or both eyes (Repka, 2020; Sandfeld et al., 2019). Significant refractive errors were defined as hyperopia exceeding +2.0 dioptres (D), at least -0.5 D of myopia, -1.0 D of astigmatism, and 1.0 D of anisometropia.

Positive predictive value (PPV) was calculated by dividing the number of children with positive screening result (i.e., measures outside the above-mentioned criteria) who received glasses (true positive) with the number of children with positive screening results (true and false positive).

Statistics

Children were divided into three groups for analysis: not referred (group 1), referred to an ophthalmologist but without having glasses prescribed (group 2), and referred and having glasses prescribed (group 3).

Normally distributed continuous data is presented as mean and standard deviation (SD), while non-normally distributed data is presented as median and interquartile range (IQR). Categorical data was tested using a non-parametric χ^2-test or Fischer's exact test when required. Paired t-test was used to compare non-cycloplegic with cycloplegic refraction (non-cycloplegic minus cycloplegic refraction).

The participation rate was determined using the number of six-year-old children in 2017 and birthrates from 2011, as obtained from Statistics Greenland (Statistics Greenland, 2024).
A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 517 (238 girls and 279 boys) children participated in the standard health screening programme conducted by school nurses. Most children (93%) were from the cities, with the remaining from smaller settlements (**Fig. 1**). The overall participation rate was 68% of the entire population of first-grade children in Greenland, but as the three northernmost cities and one on the east coast were not included in the study, the participation rate among invited children was 82%.
In total, 7% of the children (95% CI: 5-9%) had amblyopia (VA equal to or higher than 0.3 logMAR, equivalent to 6/12 Snellen fraction) in either eye, and 3% (95% CI: 2-5%) in both eyes (**Fig. 2**) at the screening (PVA). After examination by a local ophthalmologist, the corresponding measurements with BCVA were 2% (95% CI 1-3%) for either eye and 1% (95% CI 0-3%) for both eyes. Forty-four children (9% of all participating children) had an interocular VA difference (IOD) of two or more lines during the screening (**Fig. 3**). Of these, 20 children had an IOD of three or more lines. Within the follow-up period, five of these children continued to exhibit an IOD of three or more lines (BCVA). One had optic nerve anomaly, three had anisometropia of ≥3 D, one had astigmatism <-3.0 D. The remaining 15 children had the following outcomes: one child had a history of trauma to one eye; 11 children achieved normal BCVA in both eyes; one child had a BCVA of 0.2 in both eyes; one child was diagnosed with an anisometropia of 3 D and two lines of IOD; and one child's further information was unavailable.
At screening, 10% had hyperopia of >+2.0 D, 3% had myopia of ≤-0.5 D, and 14% had astigmatism of ≤-1.00 D. The corresponding numbers at the ophthalmological examinations were 8% for hyperopia, 4% for myopia, and 6% for astigmatism. For the spherical equivalent

refractions, the screening showed that 5% had hyperopia and 4% had myopia, while the ophthalmological examination revealed 6% had hyperopia and 4% had myopia.

Group 1 (462 children) were not referred to an ophthalmologist following the screening, group 2 (n=24) were referred to an ophthalmologist, but were not prescribed glasses, and group 3 (n=31) were referred to an ophthalmologist, and all were prescribed glasses.

Forty-three children (8%) had ongoing outpatient contact with an ophthalmologist or optometrist at the time of screening, of which 18 already had glasses, while two did not wear their glasses during the screening.

Overall, the children exhibited a binocular VA of 0.01 logMAR, with the worse-seeing eye at 0.07 and the better-seeing eye at 0.02. The median stereoacuity was 200 seconds of arc. Additionally, the children generally had low hyperopia and low astigmatism, as detailed in **Table 1**.

There was a significantly higher proportion of children who were prescribed glasses (group 3) compared to children who were not prescribed glasses (groups 1 and 2), with a PVA for distance ≥0.3 logMAR (p = 0.03, χ^2-test) and an interocular difference in VA >2 lines (p = 0.003, Fischer's Exact test). The two referred groups (groups 2 and 3) had a significantly higher proportion of abnormal Plusoptix measurements compared to the non-referred group (group 1), whereas no difference between the two referred groups was found. Of the 462 children in group 1, 17 had a PVA for distance of ≥0.3 logMAR. Among these, six had ongoing contact with an ophthalmologist or an optometrist, and two had a new vision screening soon after, which was normal. Within the follow-up period, seven children were seen by the local ophthalmologist, and glasses were prescribed to four of them. Two children who had not been examined by an ophthalmologist exhibited a visual acuity (VA) of 0.3 in the worse-seeing eye (with the better-seeing eye at 0.2 and 0.1, respectively). One child presented with mild hyperopia of +1.0, while the other had hyperopia of +2.5 and astigmatism of -1.5, as measured on the Plusoptix. Both children demonstrated normal near VA and stereoacuity (**Table 2**).

Of the 55 (11%) referred children from the screening, 31 (6%) were prescribed glasses. Of the 24 children who were referred but not prescribed glasses, 22 had normal vision upon re-examination, one was lost to follow-up, and one child, for reasons unknown, was not prescribed glasses despite the presence of anisometric amblyopia.

By grouping all children seen by an ophthalmologist, no significant difference was found between the non-cycloplegic and the cycloplegic refraction, except a larger astigmatism was found in cycloplegia (**Table 3**).

The positive predictive value (PPV) increased when combining multiple measurements compared to a single measurement, whereas the absolute number of children receiving glasses decreased when combining more than two measurements (**Table 4**).

DISCUSSION

The present study is the first to describe the distribution of visual acuity, refraction, and stereoacuity, and to estimate the prevalence of visual impairment in Greenlandic schoolchildren.

Although the study did not include children from four cities and their settlements, it still covered most of the large and small cities and settlements, accounting for 68% of all first-grade children. This extensive inclusion across various regions supports the representativeness of our findings, despite the exclusion of the northernmost and one eastern smaller city. The participation rate of 82% is similar to the participation rate of health examinations where vision screening is conducted among 5-year-old children in Denmark (Michelsen et al., 2007). This further supports that the estimated prevalence of visual impairment represents the first-grade Greenlandic schoolchildren.

The prevalence of monocular and binocular amblyopia verified at the ophthalmological examination was 2% and 1%, respectively, which falls in between the findings of previous studies from Denmark and Canada (Ross et al., 1977; Sandfeld et al., 2018). However, a more recent Canadian study reported a higher prevalence of amblyopia, possibly due to a different amblyopia definition (Drover et al., 2008). The tendency for a lower prevalence of amblyopia in some studies may also be due to differences in methodology. By defining amblyopia as a VA of ≥0.3 logMAR and an interocular difference of ≥2 lines, the prevalence of monocular amblyopia in our study was 3% (15/517) at the screening and after the examination by the local ophthalmologist only 1% (5/517).

In the present study, the significantly higher estimated prevalence of amblyopia detected during screenings by school nurses, compared to examinations by ophthalmologists, may be attributed to the differences between PVA and BCVA or by learning effect, which reduces the false positive rate of amblyopia as found in previous studies (Sandfeld et al., 2018). Xiao et al. (Xiao et al., 2015) demonstrated how the prevalence of amblyopia varies with different definitions. The highest prevalence is observed when defining amblyopia as BCVA ≥0.3 logMAR (approximately 3%), while the lowest was seen using The Refractive Error Study in Children's suggested criteria (<1%). In the context of Greenland, determining the appropriate criteria for treating amblyopia is critical. If a child's BCVA is at 0.3 logMAR, the decision to forgo patch treatment should be carefully considered. Given the scarcity of school nurses and ophthalmologists in Greenland, establishing a cutoff that identifies the majority of children who require ophthalmological evaluation and treatment is essential. Setting the amblyopia definition at ≥0.3 logMAR could effectively address this need.

Furthermore, significant differences were found between different ethnic groups using the same examination protocol, with lower prevalence of amblyopia for African, Nepali, Malay, and Indian children, but not for Chinese and Hispanic children (Xiao et al. 2015), suggesting that both genetics and environmental factors impact the prevalence of visual impairment.

In this study, the prevalence of myopia (≤0.50 D) was 4% (95% CI 2-6%), which is lower than in Canada (Yang et al., 2018), but higher than in Scandinavia (Bro & Löfgren, 2023; Sandfeld et al., 2018). This is similar to indigenous, but not non-indigenous people from Australia (Hopkins et al. 2016). Such diverging results further support the impact of both genetics and environment on the development of ametropia, indicating that direct comparison of prevalence should be done with caution. This is further supported by the fact that compared to our study, hyperopia and anisometropia were less frequent in indigenous compared to non-indigenous people, and the opposite was true for astigmatism (Hopkins et al., 2016). The prevalence of hyperopia, anisometropia, and astigmatism found in our study corroborates with findings from Denmark (Sandfeld et al., 2018). No studies from other Indigenous people from the circumpolar regions have been performed.

Our results show that not all children in need of ophthalmological care or evaluation would be identified by standard distance visual acuity screening alone. This implies that adding other clinical assessments to the screening protocol would increase the efficacy. As Plusoptix autorefraction appears to be highly correlated with cycloplegic refraction, and by combining distance visual acuity screening with results from Plusoptix autorefractor, it is possible to identify children with hyperopia, myopia, astigmatism, and anisometropia as shown in previous studies (Li et al., 2023; Silverstein & McElhinny, 2020). Adding stereoacuity and near visual acuity testing may further reduce the proportion of children with untreated vision anomalies, but the potential value of Plusoptix, stereoacuity and near visual acuity testing is most likely underestimated in the present study as only distance visual acuity was used as referral criterion. In our study, combining distance VA measurement with the Plusoptix autorefractor or stereoacuity appears to be the most effective combination. However, adding multiple tests to a vision screening will likely result in a higher number of false positive referrals for ophthalmological examination, thereby increasing costs and possibly delaying treatment of acute eye conditions. Retesting children who fail the initial screening before referring them to an ophthalmologist will most likely decrease false positive rates (Gyllencreutz et al., 2019).

An effective vision screening program is crucial for identifying children with refractive errors and visual impairments, which can significantly impact their daily lives and overall quality of life. Previous studies have shown that appropriate corrective measures, such as glasses, can substantially improve academic performance and general well-being (Kumaran et al., 2015; Pirindhavellie et al., 2023). However, wearing glasses may also have adverse effects, particularly in the context of physical activities and sports. Additionally, the social perceptions associated with wearing glasses in school settings may negatively affect a child's self-esteem and mental well-being (Kumaran et al., 2015). It is therefore essential to consider both the physical and psychosocial dimensions of prescribing glasses to children as part of a comprehensive vision care strategy.

Although this study suggests that the efficacy of vision screening can be enhanced, the nature of the study design only permits calculation of positive predictive values, and thereby insufficient on deciding to change the present vision screening programme. A study in Greenland, in which all children undergo the new screening method followed by a comprehensive ophthalmological examination, including cycloplegic refraction, could provide further insights into this issue.

Despite improvements, some children still receive false positive test results. However, as Greenland has no permanent ophthalmologist, an accurate first-time vision screening is essential. Children might wait for more than a year to be examined by a consultant ophthalmologist, thereby delaying amblyopia treatment, why a high sensitivity is more important than a high positive predictive value. The fact that one child with anisometropic amblyopia was not prescribed glasses highlights the need for new guidelines to standardise glasses prescriptions for all children by consulting ophthalmologists in Greenland. However, the results indicate that trained school nurses can successfully perform screenings using the HOTV chart, which has replaced the less accurate Østerberg chart as the standard visual acuity chart for school children in Greenland.

In conclusion, enhancing the utilisation of preschool vision screening for Greenlandic children is essential to identify children with amblyopia and other vision impairments, given the limited availability of eye examinations in Greenland. By combining multiple vision tests, the accuracy will be increased. Our study showed that school nurses can conduct vision screening for schoolchildren in Greenland. (Xiao et al. 2015)

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Author Contribution:

Research Design: ND, IN, MEJ, SH, HJ.

Data Acquisition/Research Execution: ND, HJ

Data Analysis/Interpretation: ND, IN, HJ, SH

Manuscript Preparation: Original Draft: ND, IN, HJ Writing, Review & Editing: ND, IN, MEJ, SH, HJ.

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Conflicts of Interest:

No conflicts of interest

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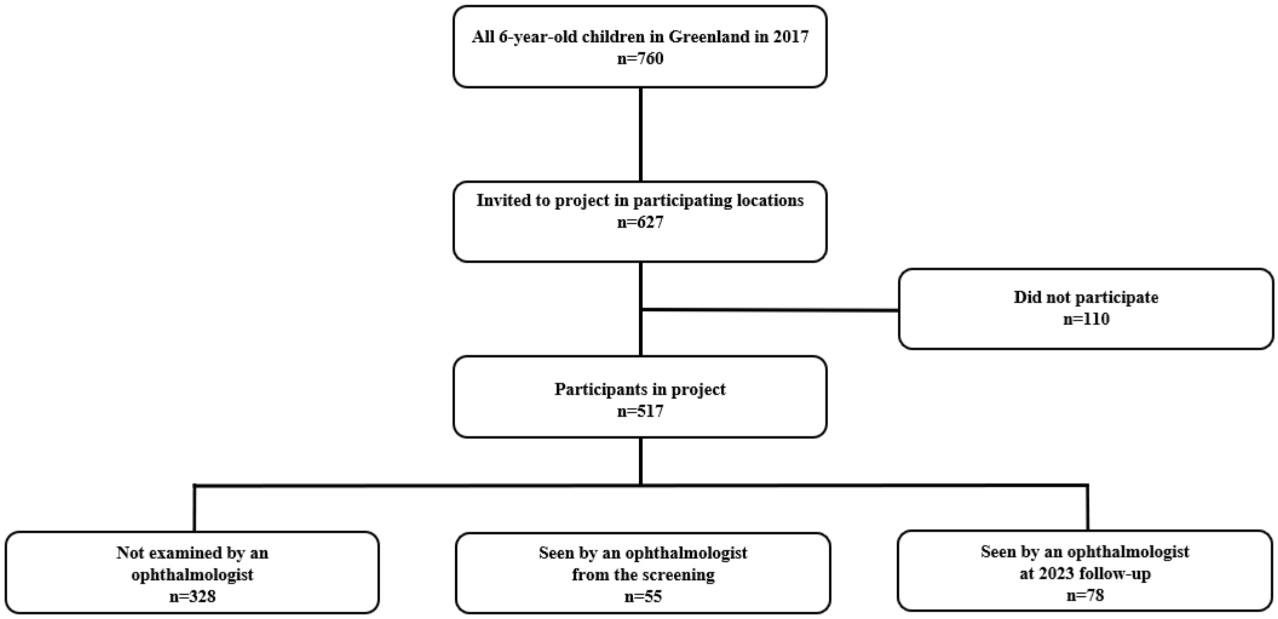

Figure 1. Flowchart of participants.

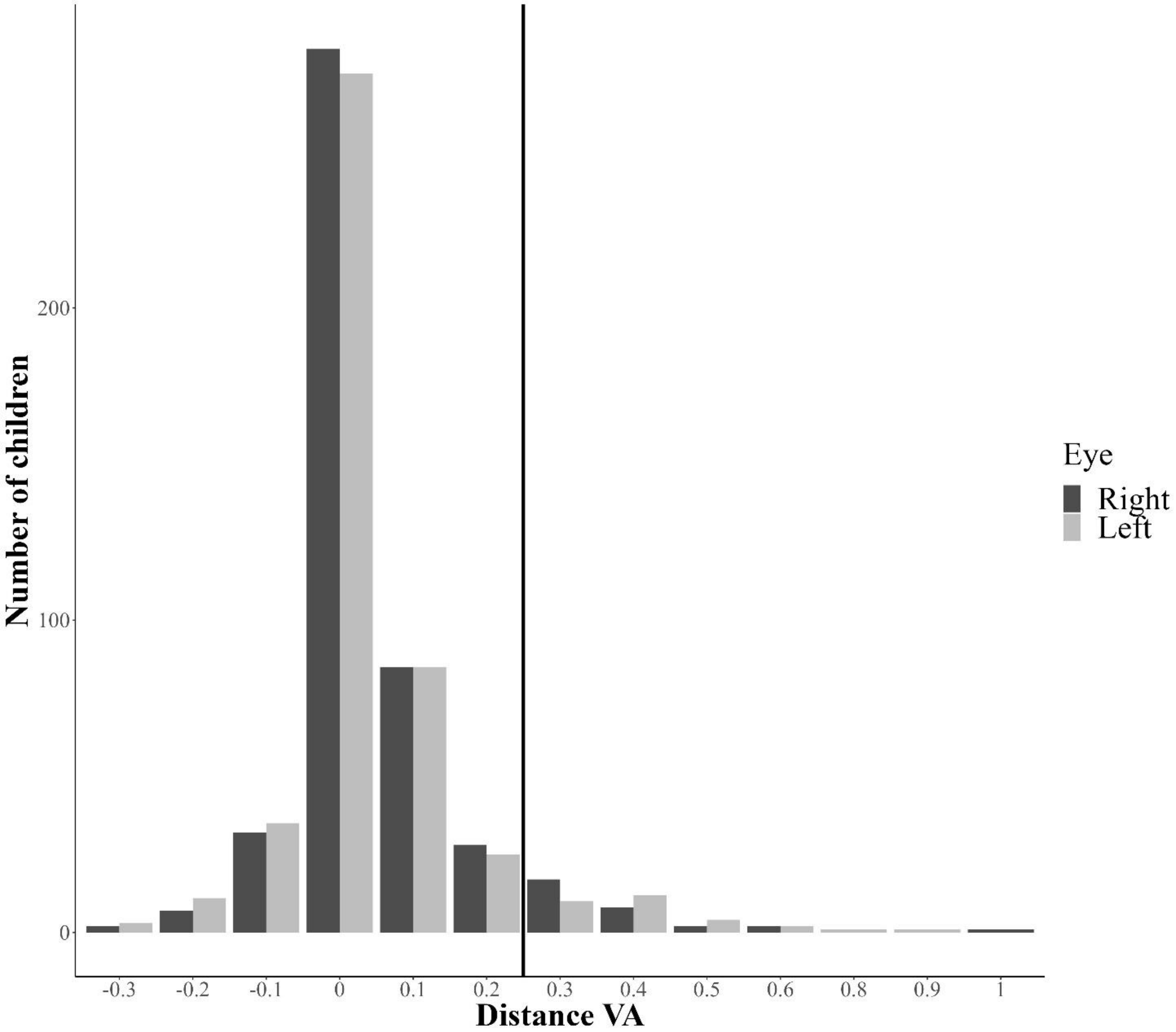

Figure 2. Distance visual acuity (VA) (logMAR) from screening of all Greenlandic children. The intercept line marks VA of 0.3 logMAR (6/12 Snellen fraction) or worse.

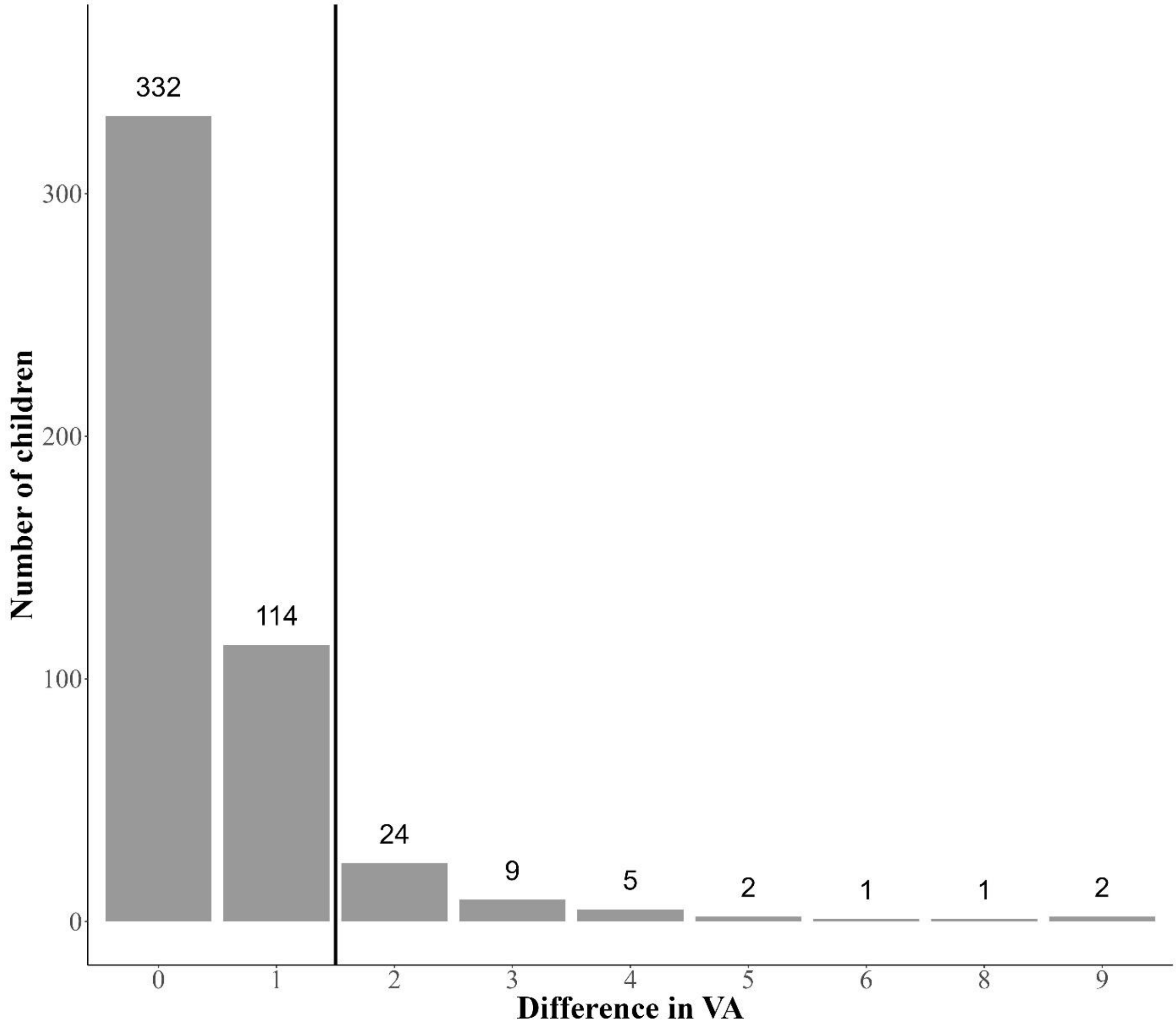

Figure 3. Number of Greenlandic children with interocular differences in visual acuity (VA) between the right and the left eye on the VA chart. The intercept line marks 2 or more lines in difference.

Table 1. Data of all Greenlandic children's vision and refraction from screening and examination.

Measurements	**All children** n = 517
Distance VA screening (logMAR)	
Binocular	0.01 (0.10)[1]
Worse eye	0.07 (0.15)[1]
Better eye	0.02 (0.10)[1]
Interocular difference in VA*	0.0 [0.0, 1.0][2]
Near binocular VA screening (logMAR)	0.01 (0.10)[1]
Lang II Test screening (seconds of arc)	200 arcsec [200, 200][2]
Plusoptix refraction (D)	
Most hyperopic sph. eye	+1.17 (0.91)[1]
Least hyperopic sph. eye	+0.85 (0.82)[1]
Most astigmatic eye	-0.50 [-0.75, -0.25][2]
Most hyperopic sph.eq. eye	+0.90 (0.81)[1]
Least hyperopic sph.eq. eye	+0.61 (0.75)[1]
Spherical equivalent right eye	+0.72 (0.79)[1]
Spherical equivalent left eye	+0.79 (0.78)[1]
Sph.eq. diff.	-0.07 (0.42)[1]
Cycloplegic refraction (D)	
Most hyperopic sph. eye	+1.97 (2.53)[1]
Least hyperopic sph. eye	+1.25 (2.47)[1]
Most astigmatic eye	-0.75 [-1.50, -0.25][2]
Most hyperopic sph.eq. eye	+1.72 (2.53)[1]
Least hyperopic sph.eq. eye	+1.19 (2.68)[1]
Spherical equivalent right eye	+1.17 (2.74)[1]
Spherical equivalent left eye	+1.65 (±2.50)[1]
Sph.eq. diff.	-0.41 (1.44)[1]

VA = Visual Acuity, D = dioptres
*Interocular difference in VA in number of lines.
sph. = Spherical, sph.eq. = Spherical equivalent
Sph.eq. diff. = Spherical equivalent difference between the eyes
[1]Mean (Standard Deviation)
[2]Median [25% and 75 % Interquartile]

Table 2. Number and proportion of Greenlandic children with specific findings within the three groups.

	Group 1 N=462 (%)	Group 2 N=24 (%)	Group 3 N=31 (%)	p-value	p-value Group 2 vs Group 3
VA					
Distance ≥0.3 worse eye	17 (4)	11 (46)	22 (71)	**<0.001**[1]	**0.03**[1]
Near ≥0.3 binocular	8 (2)	3 (13)	4 (13)	**<0.001**[2]	1.0[2]
≥2-line diff. in VA	19 (4)	3 (13)	15 (48)	**<0.001**[2]	**0.003**[2]
Plusoptix					
Abnormal*	91 (20)	13 (54)	15 (48)	**<0.001**[1]	0.71[1]
No Plusoptix measurements	55 (12)	1 (4)	13 (42)		
Lang II Test >400 arcsec	12 (3)	4 (17)	8 (26)	**<0.001**[2]	0.35[2]

VA = Visual Acuity (logMAR), diff. = difference, D = dioptres
[1]χ^2-test
[2]Fischer's Exact test
*Hyperopia >+2.00 Dioptres (D), myopia ≤-0.50 D, astigmatism ≤-1.00 D or anisometropia
Dioptres in spherical/cylindrical
Group 1: Not referred.
Group 2: Referred but not prescribed glasses.
Group 3: Referred and prescribed glasses.

Table 3. Non-cycloplegic (Plusoptix) refraction vs. Cycloplegic refraction of Greenlandic children seen by an ophthalmologist (n=133).

Measurements	Mean difference	95% CI	p-value[1]
Spheric right eye (D)	+0.11	-0.25, 0.47	0.55
Spheric left eye (D)	+0.21	-0.16, 0.59	0.26
Cylinder right eye (D)	-0.07	-0.25, 0.11	0.45
Cylinder left eye (D)	-0.22	-0.38, -0.06	**0.008**

[1]Paired t-test
D = Dioptres in spherical/cylindrical
95% CI = 95% Confidence Intervals
Mean difference calculated as non-cycloplegic minus cycloplegic refra

Table 4. Positive predictive value (PPV) of screening methods.

	PPV
One measurement	
Distance VA ≥0.2 worse eye (logMAR)	0.40 (33/83)
≥2-line difference in VA	0.43 (16/37)
Distance VA ≥0.2 worse eye (logMAR) & ≥2-line difference in VA	0.52 (15/29)
Near VA ≥0.2 binocular (logMAR)	0.23 (7/31)
Abnormal Plusoptix‡	0.41 (28/68)
Lang II Test >400 arcsec	0.50 (12/24)
Combining two measurements	
Distance VA ≥0.2 & Near VA ≥0.2 binocular	0.37 (7/19)
Distance VA ≥0.2 & Lang II Test >400 arcsec	0.64 (9/14)
Distance VA ≥0.2 & Abnormal Plusoptix‡	0.57 (21/37)
Near VA ≥0.2 binocular logMAR & Lang II Test >400 arcsec	0.50 (3/6)
Near VA ≥0.2 binocular logMAR & Abnormal Plusoptix‡	0.55 (6/11)
Lang II Test >400 arcsec & Abnormal Plusoptix‡	0.67 (4/6)
Combining three measurements	
Distance VA ≥0.2 & Near VA ≥0.2 binocular & Lang II Test >400 arcsec	0.60 (3/5)
Distance VA ≥0.2 & Near VA ≥0.2 binocular & Abnormal Plusoptix‡	0.67 (6/9)
Distance VA ≥0.2 & Lang II Test >400 arcsec & Abnormal Plusoptix‡	0.75 (3/4)
Near VA ≥0.2 binocular & Lang II Test >400 arcsec & Abnormal Plusoptix‡	1.00 (2/2)
Combining all four measurements	
Distance VA ≥0.2 & Near VA ≥0.2 binocular & Lang II Test >400 arcsec & Abnormal Plusoptix	1.00 (2/2)

VA = Visual Acuity (logMAR)

‡ Hyperopia >+2.00 D, myopia ≤-0.5 D, astigmatism ≤-1.00 D or anisometropia ≥1.00 D

Paper III

VISUAL PROFILING AND VISION SCREENING OF PRESCHOOL CHILDREN IN GREENLAND

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ABSTRACT

Purpose: To establish normative data on refraction and visual acuity for preschool children without prior contact with eye care professionals in Greenland and develop a practical vision screening method tailored to Greenlandic healthcare needs.

Methods: A population-based cross-sectional study was conducted in six towns in Greenland, involving 274 children born in 2017 attending kindergartens. Each child underwent vision screening by an optometrist, including assessments of binocular and monocular distance visual acuity (VA) using Kay Pictures, binocular near VA with Lea Symbols, stereoacuity with a Lang II Test, and non-cycloplegic refraction using the Plusoptix A12R. An ophthalmologist conducted follow-up eye examinations, including cycloplegic refraction, within one week.

Results: Out of 532 eligible children, 274 participated in the screening and the ophthalmological examination. The overall mean VA for the worse- and best-seeing eye was 0.05 (±0.16 SD) and 0.01 (±0.12 SD) logMAR. Myopia (≤-0.5 diopters (D)) was found in 5%, emmetropia and mild hyperopia (-0.25 - +2.0 D) in 67%, and hyperopia >+2.0 D in 18% of the children. With-the-rule astigmatism was the most common axis ($\chi 2$-test, $p<0.01$). Vision screening using the Plusoptix autorefractor and distance VA test had the best sensitivity and specificity for identifying children requiring further ophthalmological evaluation.

Conclusions: Most preschool children in Greenland exhibit good visual acuity and predominantly mild hyperopia. Vision screening by Greenlandic optometrists using the Plusoptix autorefractor and distance VA assessments in kindergartens improves the detection of children needing ophthalmological evaluation. This method is recommended for widespread adoption in Greenland to enhance early detection and treatment outcomes.

Keywords: Arctic, Preschool Children, Refraction, Vision Screening, Visual Acuity

INTRODUCTION

Greenland's healthcare system proposes conducting the first vision screening of preschool children at the age of four as part of routine health examinations in accordance with global recommendations (Government of Greenland 2005, WHO 2024). 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 (Eibschitz-Tsimhoni et al., 2000; Holmes et al., 2011; Jonas et al., 2017).

Greenland is the world's largest island with a predominantly Inuit population, where specialized healthcare services, including ophthalmology, face great challenges. The absence of a permanent ophthalmologist, combined with regions without healthcare professionals specialized in children's health across the vast and sparsely populated territories, severely limits children's access to regular eye examinations. Despite these challenges, Greenland has eleven local optometrists in three towns, travelling annually to all towns and some settlements. However, these optometrists do not routinely examine children as part of their daily practice. This limitation highlights a significant lack of accessible healthcare, a challenge not unique to Greenland but also observed in other regions within the circumpolar area (Keenan et al., 2023; Mema et al., 2012; Young et al., 2020). 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 (Asare et al., 2017; Fogel-Levin et al., 2016; Ugurbas et al. 2019).

The effectiveness and participation rates of Greenland's current vision screening program remain unclear. However, Duelund et al. 2024 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.

METHODS

Design

The study was designed as a population-based cross-sectional study conducted in three representative towns with local optometrists and three representative towns without access to optometrists in four of the five regions in Greenland (**Fig. 1)**.

Study population

Children born in 2017 attending kindergarten in the six towns were invited to participate (**Fig. 2)**. 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 before written consent was obtained from the parents. The exclusion criterion was known eye disease already under the care of an ophthalmologist. 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 or one travelling from Nuuk. 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 meters (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 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 (Plusoptix GmbH, Nuremberg, Germany).

The subsequent eye examination was conducted at the local hospital one to seven days after the vision screening. The same ophthalmologist (principal investigator) examined all children. The examination mirrored the screening assessments and included additional tests for strabismus, slit lamp examination, ophthalmoscopy in cycloplegia, and autorefraction in cycloplegia (30 minutes after two drops of 1% Cyclopentolate) using a handheld Nidek HandyRef-K autorefractor (Nidek Co. Ltd., Gamagori, Japan). The prescription of glasses followed guidelines established by the American Association for Pediatric Ophthalmology and Strabismus (AAPOS) (Arnold et al. 2022), although the final decision to prescribe glasses was always individualized.

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 refraction for both eyes.

Statistical analysis

Normally distributed continuous data were summarized 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 analyzed with the Stuart-Maxwell test.

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

The participation rate was calculated using data from Statistics Greenland ('Statistics Greenland' 2024).

RESULTS

The number of children qualified to participate in this project was 532, 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 (**Fig. 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 approximately a logMAR value of 0.0, while measurements for near VA averaged 0.11. At the ophthalmological examination, monocular distance and near VA measurements were significantly worse than those obtained at the screening, although the differences were minor.

The non-cycloplegic refractions obtained from the Plusoptix at the screening showed a lower magnitude of hyperopia and myopia compared to the cycloplegic refractions measured at the ophthalmological examination. The axes of the astigmatism measured by the Plusoptix were equally distributed among with-the-rule, against-the-rule, and oblique (Gwiazda et al. 1984) (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 visual acuity (VA) for the worse-seeing eye was the single measure that showed the highest sensitivity for the need for referral to an ophthalmologist, 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 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) (**Fig. 5a**, **Fig. 5b**). Utilizing these ROC curves, optimal cutoffs 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.

At the screening, a lower proportion of children had visual acuity of 0.2 logMAR or worse than at the ophthalmological examination (40/266 vs 47/266) (**Fig. 3**). The majority of the children were emmetropic or had mild hyperopia and more children had high hyperopia in cycloplegia (**Fig. 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 having iris coloboma, and ten children had persistent pupillary membranes as a single string. Nine children had insufficient convergence (≥10 cm from the nose).

Two children with anisometropic amblyopia, who initially presented with visual acuities of 1.0 and 0.5 logMAR at screening, underwent patch treatment. One year after the treatment, both children improved their visual acuities to 0.4 and 0.3 logMAR, respectively.

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 ('Statistics Greenland' 2024), 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 generalized to preschool children in Greenland.

Distance VA was assessed with Kay Pictures to reduce completion failure while maintaining good test-retest variability (Jones et al., 2003; Leone et al., 2012; Shah et al., 2012). 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 (Asare et al., 2017; Hunter et al., 2022; Wilson et al., 2022). The Lang II Test was used to examine if the sensitivity of the screening method could be increased, as the Lang II Test is not suitable for vision screening as a standalone test (Afsari et al., 2013; Huynh et al., 2005; Ohlsson et al., 2002).

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 (Leone et al., 2014; Pan et al., 2009; Sandfeld et al., 2018). 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 (Fan et al. 2011, Giordano et al. 2009, Sandfeld et al. 2018), 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 (Cowen & Bobier 2003, Dobson et al. 1999, Fan et al. 2004). 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 (WHO 2024). However, adopting this cutoff 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 (**Fig. 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 while adding near VA and stereoacuity to distance VA did not increase the sensitivity.

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 negatives. 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**). Re-testing children who initially display abnormal VA or non-cycloplegic autorefraction before referring will most likely reduce the referral rate significantly to an even more acceptable absolute number (Shah et al. 2012). Adding near VA to distance VA and non-cycloplegic refraction with the Plusoptix increased sensitivity to 94% (**Table 2**); however, as the children had difficulty maintaining the 40 cm testing distance, using near VA for screening proved too inaccurate.

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 (Duelund et al. 2024). Limited attention to vision screening programs is not unique to Greenland (Donaldson, Subramanian & Conway 2018, Masarwa et al. 2023), suggesting that repetition of systematic information about health examination is warranted to increase awareness. 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. We recommend providing ongoing information about the program to increase participation rates in Greenland's vision screening program. Enhancing the sensitivity of the vision screening can be achieved by having Greenlandic optometrists perform distance VA measurements in conjunction with using the Plusoptix autorefractor in kindergartens.

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Author Contribution:

Research Design: ND, IN, MEJ, SH, HJ.

Data Acquisition/Research Execution: ND.

Data Analysis/Interpretation: ND, IN, HJ.

Manuscript Preparation: Original Draft: ND, Writting, Review & Editing: ND, IN, MEJ, SH, HJ.

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Conflicts of Interest:

No conflicts of interest

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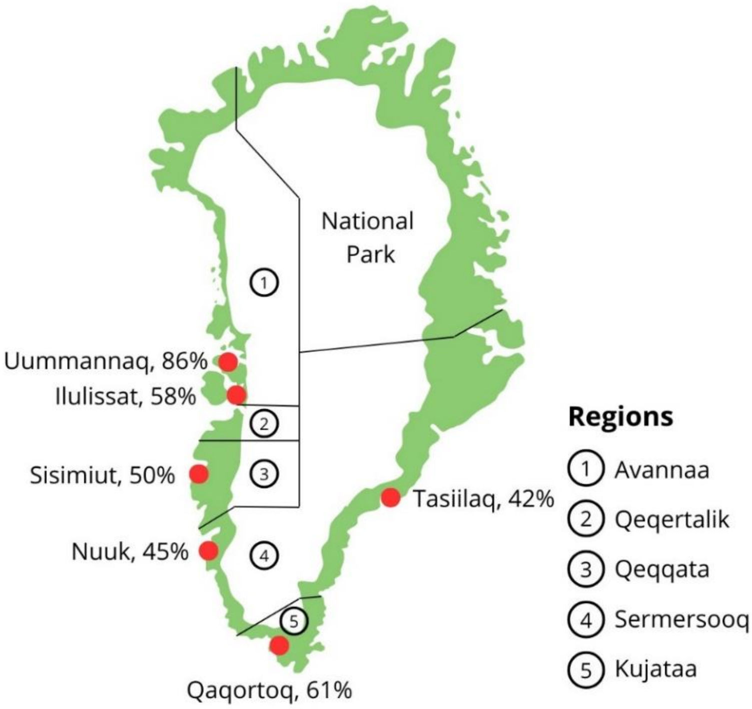

Figure 1. Map of Greenland highlighting the regions and towns visited for this study, labelled with the participation rates in each location, expressed as percentages of the 5-year-old children as of January 1, 2023.

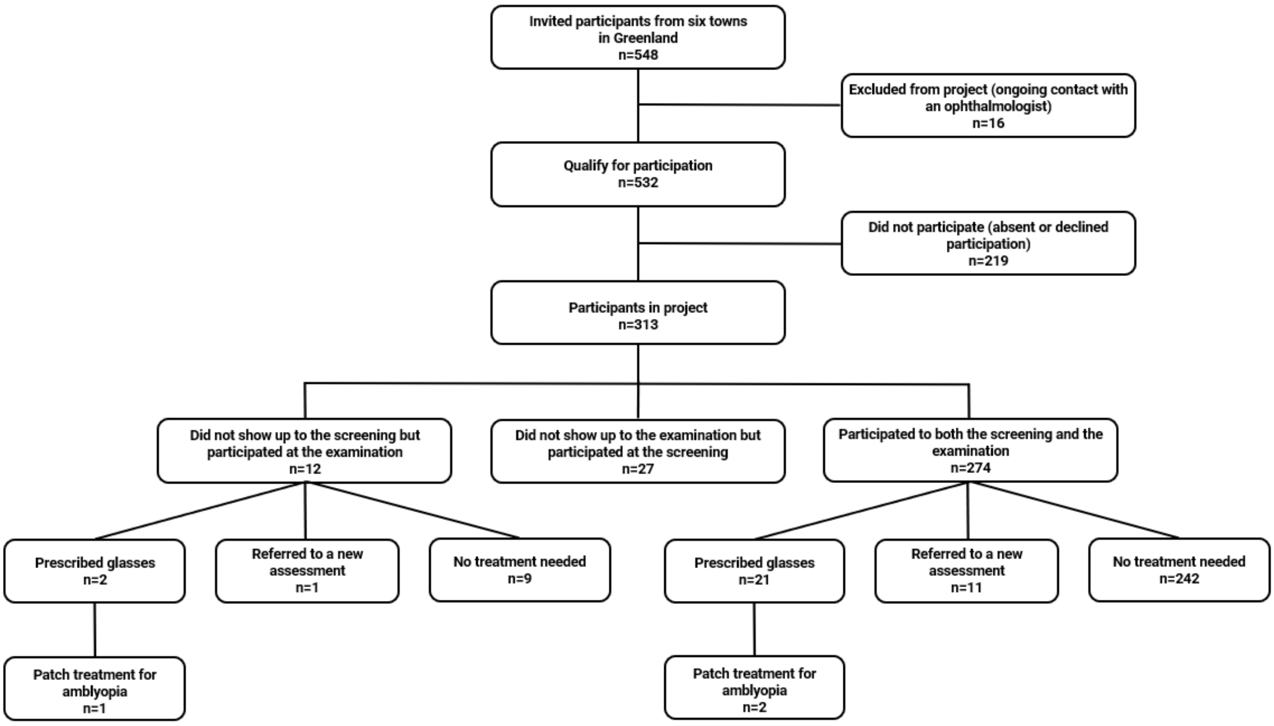

Figure 2. Flowchart showing participants in this study.

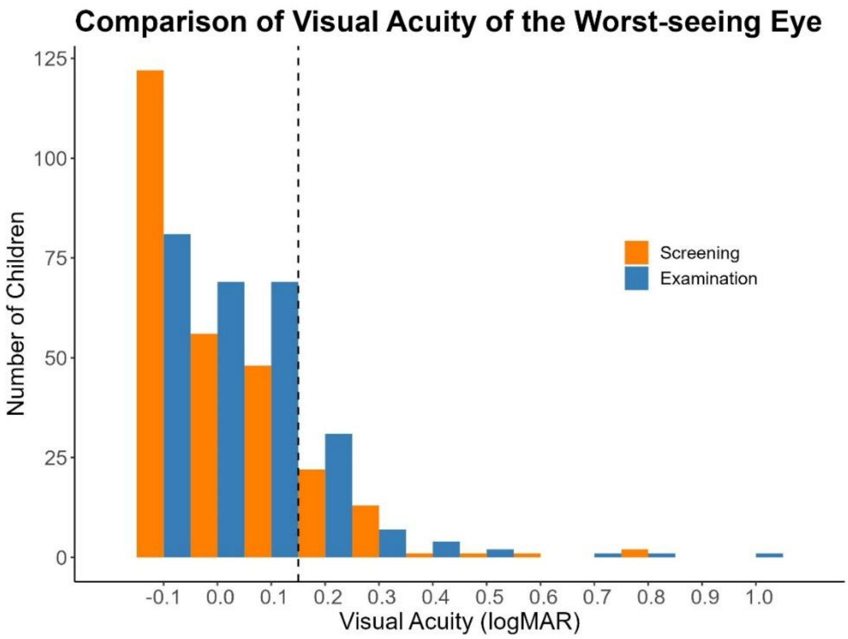

Figure 3. Visual acuity (VA) measurements of the worst-seeing eyes measured at the screening (orange) and at the ophthalmological examination (blue). The dashed line marks a VA of 0.2 logMAR or above to illustrate the number of visually impaired children in Greenland.

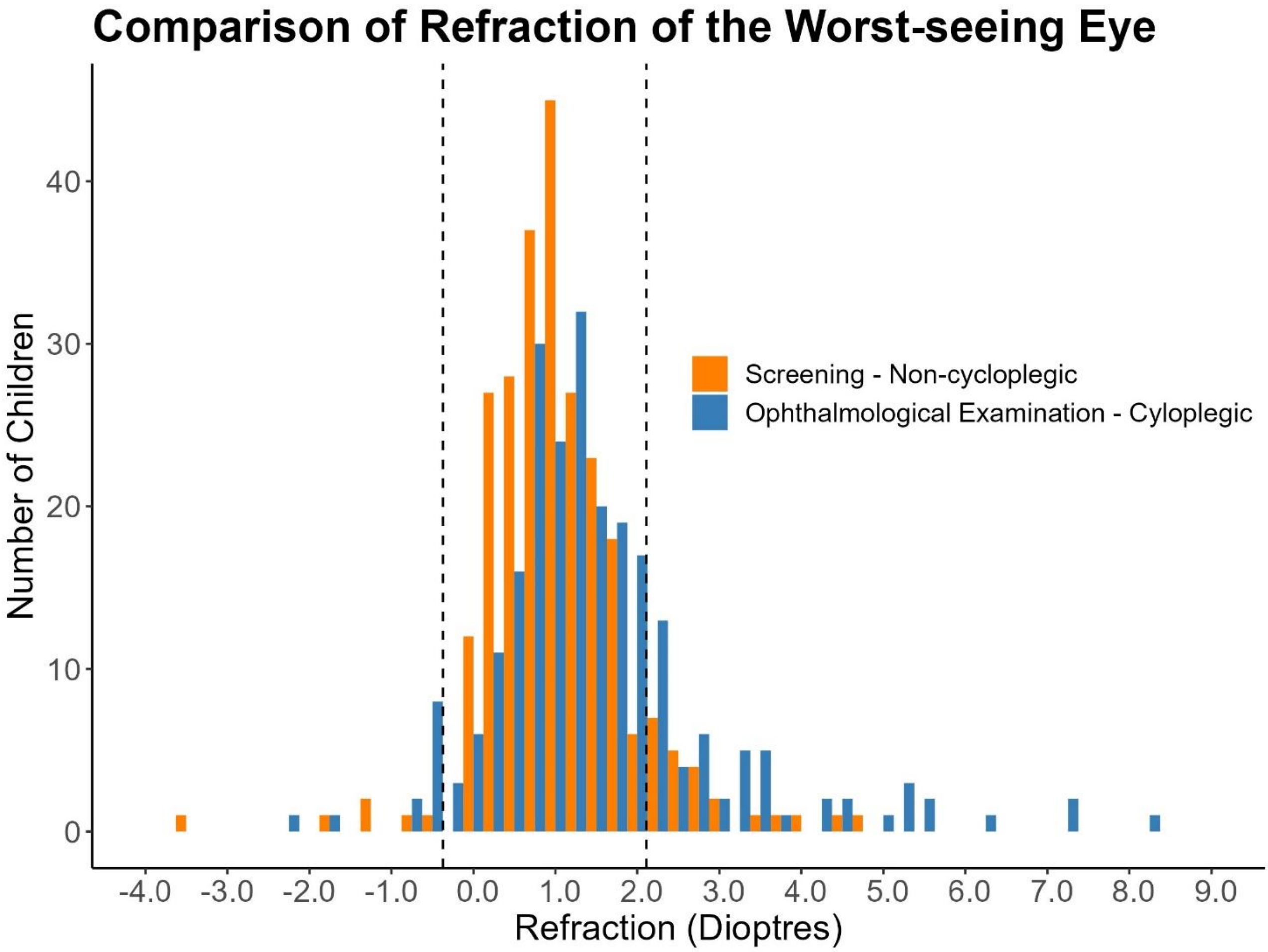

Figure 4. Non-cycloplegic refractions measured using the PlusoptiX A12R during the screening (orange), and cycloplegic refractions obtained from the ophthalmological examination (blue). The cycloplegic refractions were more hyperopic, indicating that the Plusoptix underestimates high hyperopia.
The dashed lines mark refractions between -0.25 and +2.0 diopters.

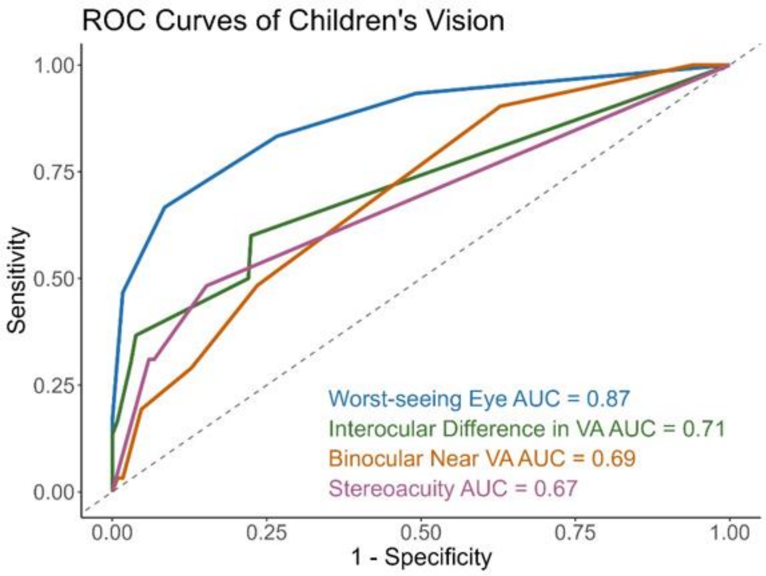

Figure 5a.

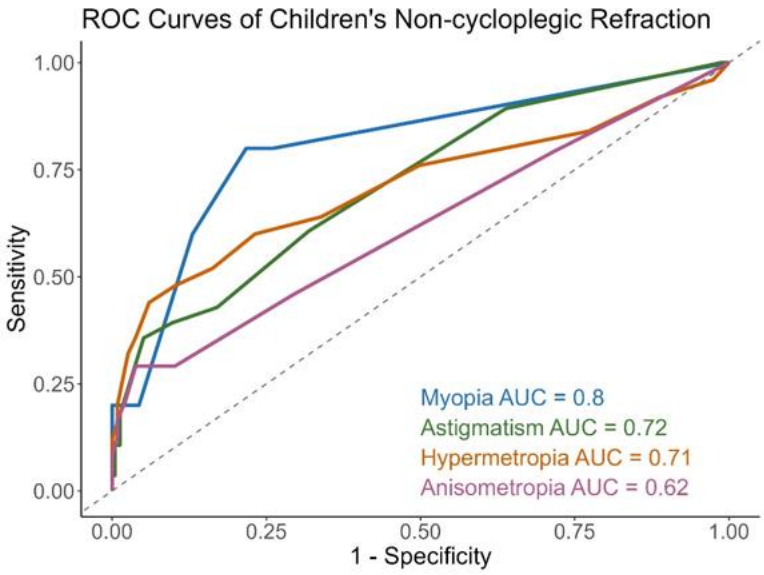

Figure 5b.

Figures 5a and 5b: 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 diopters (D), Myopia ≤0 D, Astigmatism ≤0 D, and Anisometropia ≥0 D.

VA = Visual acuity

Table 1. Data from the screening versus ophthalmological examination

Measurement	Screening	Eamination	Mean Differenc e	95% Confidence Interval	p-value
Visual acuity logMAR					
Binocular (3m)	-0.04 ± 0.10	-0.03 ± 0.11	-0.01	-0.01, +0.01	0.48[1]
Worst-seeing eye (3m)	0.02 ± 0.15	0.05 ± 0.16	-0.03	-0.04, -0.01	**<0.001**[1]
Best-seeing eye (3m)	-0.02 ± 0.11	0.01 ± 0.12	-0.03	-0.04, -0.02	**<0.001**[1]
Binocular near (0.4m)	0.11 ± 0.14	0.13 ± 0.09	-0.02	-0.03, -0.001	**0.04**[1]
Refraction in diopters					
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	-0.26	-0.38, -0.13	**<0.001**[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"	n = 235	n = 243			
400"	n = 27	n = 19			
600"	n = 2	n = 3			
>600''	n = 25	n = 14			

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 Pediatric Vision Screening Methods for Referral Necessity.
Threshold: Visual Acuity of 0.2 logMAR and abnormal Plusoptix‡

	Sensitivity	Specificity
One measurement		
Distance VA*	0.72 (23/32)	0.91 (220/242)
Near VA ≥0.2 binocular (logMAR)	0.47 (15/32)	0.77 (187/242)
Abnormal Plusoptix‡	0.53 (17/32)	0.78 (189/242)
Lang II Test >400''	0.28 (9/32)	0.93 (226/242)
At least one abnormal result of two measurement		
Distance VA* **OR** Near VA ≥0.2 binocular	0.81 (26/32)	0.72 (175/242)
Distance VA* **OR** Abnormal Plusoptix‡	0.89 (28/32)	0.70 (171/242)
Distance VA* **OR** Lang II Test >400''	0.72 (23/32)	0.88 (213/242)
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)
Distance VA* **OR** Near VA ≥0.2 binocular **OR** Lang II Test >400''	0.84 (27/32)	0.68 (164/242)
Distance VA* **OR** Lang II Test >400'' **OR** Abnormal Plusoptix‡	0.88 (28/32)	0.66 (159/242)
At least one abnormal result of four measurement		
Distance VA* **OR** Near VA ≥0.2 binocular **OR** Lang II Test >400'' **OR** Abnormal Plusoptix‡	0.94 (30/32)	0.55 (125/242)

	PPV	NPV
One measurement		
Distance VA*	0.51 (23/45)	0.96 (220/229)
Near VA ≥0.2 binocular (logMAR)	0.21 (15/70)	0.92 (187/204)
Abnormal Plusoptix‡	0.24 (17/70)	0.93 (189/204)
Lang II Test >400''	0.36 (9/25)	0.91 (226/249)
At least one abnormal result of two measurement		
Distance VA* **OR** Near VA ≥0.2 binocular	0.28 (26/93)	0.97 (175/181)
Distance VA* **OR** Abnormal Plusoptix‡	0.29 (28/99)	0.98 (171/175)
Distance VA* **OR** Lang II Test >400''	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‡	0.22 (30/138)	0.99 (134/136)
Distance VA* **OR** Near VA ≥0.2 binocular **OR** Lang II Test >400''	0.26 (27/105)	0.97 (164/169)
Distance VA* **OR** Lang II Test >400'' **OR** Abnormal Plusoptix‡	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'' **OR** Abnormal Plusoptix‡	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

Supplementary I

Efficacy of screening method with different cut-offs (III):

Table 1a. Efficacy of Pediatric Vision Screening Methods for Referral Necessity.
Threshold: Visual Acuity of 0.2 logMAR and abnormal Plusoptix‡

	Sensitivity	Specificity	PPV	NPV
One measurement				
Distance VA ≥0.2 binocular (logMAR)	0.20 (7/35)	0.98 (247/251)	0.64 (7/11)	0.90 (247/275)
Distance VA ≥0.2 monocular worse eye (logMAR)	0.57 (20/35)	0.92 (231/251)	0.50 (20/40)	0.94 (231/246)
≥2-line difference in VA	0.26 (9/35)	0.97 (244/251)	0.56 (9/16)	0.90 (244/270)
Distance VA ≥0.2 worse eye (logMAR) & ≥2-line difference in VA	0.17 (6/35)	0.98 (246/251)	0.55 (6/11)	0.89 (246/275)
Near VA ≥0.2 binocular (logMAR)	0.43 (15/35)	0.78 (196/251)	0.21 (15/70)	0.91 (196/216)
Abnormal Plusoptix‡	0.49 (17/35)	0.79 (198/251)	0.24 (17/70)	0.92 (198/216)
Lang II Test >400’’	0.26 (9/35)	0.94 (235/251)	0.35 (9/25)	0.90 (235/261)
Combining two measurements				
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular	0.31 (11/35)	0.96 (241/251)	0.52 (11/21)	0.91 (241/265)
Distance VA ≥0.2 worse eye & Lang II Test >400’’	0.20 (7/35)	0.99 (249/251)	0.78 (7/9)	0.90 (249/277)
Distance VA ≥0.2 worse eye & Abnormal Plusoptix‡	0.31 (11/35)	0.99 (248/251)	0.79 (11/14)	0.91 (248/272)
Near VA ≥0.2 binocular logMAR & Lang II Test >400’’	0.11 (4/35)	0.98 (246/251)	0.44 (4/9)	0.89 (246/277)
Near VA ≥0.2 binocular logMAR & Abnormal Plusoptix‡	0.20 (7/35)	0.96 (241/251)	0.41 (7/17)	0.90 (241/269)
Lang II Test >400’’ & Abnormal Plusoptix‡	0.11 (4/35)	0.99 (248/251)	0.57 (4/7)	0.89 (248/279)
Combining three measurements				
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular & Lang II Test >400’’	0.09 (3/35)	0.99 (249/251)	0.60 (3/5)	0.89 (249/281)
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular & Abnormal Plusoptix‡	0.17 (6/35)	0.99 (249/251)	0.75 (6/8)	0.90 (249/278)
Distance VA ≥0.2 worse eye & Lang II Test >400’’ & Abnormal Plusoptix‡	0.09 (3/35)	1.00 (250/251)	0.75 (3/4)	0.89 (250/282)
Near VA ≥0.2 binocular & Lang II Test >400’’ & Abnormal Plusoptix‡	0.06 (2/35)	1.00 (250/251)	0.67 (2/3)	0.88 (250/283)
Combining all four measurements				
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular & Lang II Test >400’’ & Abnormal Plusoptix	0.06 (2/35)	1.00 (250/251)	0.67 (2/3)	0.88 (250/283)

VA = Visual Acuity (logMAR)
‡ Hyperopia >+2.00 D, myopia ≤-0.5 D, astigmatism ≤-1.00 D or anisometropia ≥1.00 D

Table 1b. Efficacy of Pediatric Vision Screening Methods for Referral Necessity.
Threshold: Visual Acuity of 0.3 logMAR and abnormal Plusoptix‡

	Sensitivity	Specificity	PPV	NPV
One measurement				
Distance VA ≥0.3 binocular (logMAR)	0.09 (3/35)	0.99 (249/251)	0.60 (3/5)	0.88 (249/282)
Distance VA ≥0.3 monocular worse eye (logMAR)	0.40 (14/35)	0.98 (247/251)	0.77 (14/18)	0.92 (247/268)
≥2-line difference in VA	0.26 (9/35)	0.97 (244/251)	0.56 (9/16)	0.90 (244/270)
Distance VA ≥0.3 worse eye (logMAR) & ≥2-line difference in VA	0.14 (5/35)	1.00 (251/251)	1.00 (5/5)	0.89 (251/281)
Near VA ≥0.3 binocular (logMAR)	0.26 (9/35)	0.88 (221/251)	0.23 (9/39)	0.89 (221/247)
Abnormal Plusoptix‡	0.49 (17/35)	0.79 (198/251)	0.24 (17/70)	0.92 (198/216)
Lang II Test >400’’	0.26 (9/35)	0.94 (235/251)	0.35 (9/25)	0.90 (235/261)
Combining two measurements				
Distance VA ≥0.3 & Near VA ≥0.3 binocular	0.11 (4/35)	0.99 (248/251)	0.57 (4/7)	0.89 (248/279)
Distance VA ≥0.3 & Lang II Test >400’’	0.20 (7/35)	1.00 (250/251)	0.88 (7/8)	0.90 (250/278)
Distance VA ≥0.3 & Abnormal Plusoptix‡	0.26 (9/35)	1.00 (250/251)	0.90 (9/10)	0.91 (250/276)
Near VA ≥0.3 binocular logMAR & Lang II Test >400’’	0.11 (4/35)	0.98 (246/251)	0.44 (4/9)	0.89 (246/277)
Near VA ≥0.3 binocular logMAR & Abnormal Plusoptix‡	0.11 (4/35)	0.98 (245/251)	0.40 (4/10)	0.89 (245/276)
Lang II Test >400’’ & Abnormal Plusoptix‡	0.11 (4/35)	0.99 (248/251)	0.57 (4/7)	0.89 (248/279)
Combining three measurements				
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular & Lang II Test >400’’	0.06 (2/35)	1.00 (250/251)	0.67 (2/3)	0.88 (250/283)
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular & Abnormal Plusoptix‡	0.06 (2/35)	1.00 (251/251)	1.00 (2/2)	0.88 (251/284)
Distance VA ≥0.3 worse eye & Lang II Test >400’’ & Abnormal Plusoptix‡	0.09 (3/35)	1.00 (251/251)	1.00 (3/3)	0.89 (251/283)
Near VA ≥0.3 binocular & Lang II Test >400’’ & Abnormal Plusoptix‡	0.03 (1/35)	1.00 (251/251)	1.00 (1/1)	0.88 (251/285)
Combining all four measurements				
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular & Lang II Test >400’’ & Abnormal Plusoptix	0 (0/35)	1.00 (251/251)	1.00 (1/1)	0.88 (251/285)

VA = Visual Acuity (logMAR)
‡ Hyperopia >+2.00 D, myopia ≤-0.5 D, astigmatism ≤-1.00 D or anisometropia ≥1.00 D

Table 1c. Efficacy of Pediatric Vision Screening Methods for Referral Necessity.
Threshold: Visual Acuity of 0.2 logMAR and abnormal Plusoptix AAPOS thresholds

	Sensitivity	**Specificity**	**PPV**	**NPV**
One measurement				
Distance VA ≥0.2 binocular (logMAR)	0.20 (7/35)	0.98 (247/251)	**0.64 (7/11)**	0.90 (247/275)
Distance VA ≥0.2 monocular worse eye (logMAR)	**0.57 (20/35)**	0.92 (231/251)	0.50 (20/40)	0.94 (231/246)
≥2-line difference in VA	0.26 (9/35)	0.97 (244/251)	0.56 (9/16)	0.90 (244/270)
Distance VA ≥0.2 worse eye (logMAR) & ≥2-line difference in VA	0.17 (6/35)	0.98 (246/251)	0.55 (6/11)	0.89 (246/275)
Near VA ≥0.2 binocular (logMAR)	**0.43 (15/35)**	0.78 (196/251)	0.21 (15/70)	0.91 (196/216)
Abnormal Plusoptix[‡]	0.31 (11/35)	0.98 (246/251)	**0.69 (11/16)**	0.91 (246/270)
Lang II Test >400''	0.26 (9/35)	0.94 (235/251)	0.35 (9/25)	0.90 (235/261)
Combining two measurements				
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular	0.11 (4/35)	0.99 (248/251)	0.57 (4/7)	0.89 (248/279)
Distance VA ≥0.2 worse eye & Lang II Test >400''	0.20 (7/35)	1.00 (250/251)	0.88 (7/8)	0.90 (250/278)
Distance VA ≥0.2 worse eye & Abnormal Plusoptix[*]	**0.20 (7/35)**	1.00 (251/251)	**1.00 (7/7)**	0.90 (251/279)
Near VA ≥0.2 binocular logMAR & Lang II Test >400''	0.11 (4/35)	0.98 (246/251)	0.44 (4/9)	0.89 (246/277)
Near VA ≥0.2 binocular logMAR & Abnormal Plusoptix[*]	**0.11 (4/35)**	1.00 (251/251)	**1.00 (4/4)**	0.89 (251/282)
Lang II Test >400'' & Abnormal Plusoptix[*]	0.09 (3/35)	1.00 (251/251)	1.00 (3/3)	0.89 (251/283)
Combining three measurements				
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular & Lang II Test >400''	0.09 (3/35)	0.99 (249/251)	0.60 (3/5)	0.89 (249/281)
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular & Abnormal Plusoptix[*]	0.11 (4/35)	1.00 (251/251)	1.00 (4/4)	0.89 (251/282)
Distance VA ≥0.2 worse eye & Lang II Test >400'' & Abnormal Plusoptix[*]	0.06 (2/35)	1.00 (251/251)	1.00 (2/2)	0.88 (251/284)
Near VA ≥0.2 binocular & Lang II Test >400'' & Abnormal Plusoptix[*]	0.03 (1/35)	1.00 (251/251)	1.00 (1/1)	0.88 (251/285)
Combining all four measurements				
Distance VA ≥0.2 worse eye & Near VA ≥0.2 binocular & Lang II Test >400'' & Abnormal Plusoptix[*]	0.03 (1/35)	1.00 (251/251)	1.00 (1/1)	0.88 (251/285)

VA = Visual Acuity (logMAR)
[*] Hyperopia >+4.00 D, Myopia < -2.00 D, Astigmatism ≤ -1.75 D or anisometropia >1.25 D

Table 1d. Efficacy of Pediatric Vision Screening Methods for Referral Necessity.
Threshold: Visual Acuity of 0.3 logMAR and abnormal Plusoptix AAPOS thresholds

	Sensitivity	Specificity	PPV	NPV
One measurement				
Distance VA ≥0.3 binocular (logMAR)	0.09 (3/35)	0.99 (249/251)	0.60 (3/5)	0.88 (249/282)
Distance VA ≥0.3 monocular worse eye (logMAR)	**0.40 (14/35)**	0.98 (247/251)	**0.77 (14/18)**	0.92 (247/268)
≥2-line difference in VA	0.26 (9/35)	0.97 (244/251)	0.56 (9/16)	0.90 (244/270)
Distance VA ≥0.3 worse eye (logMAR) & ≥2-line difference in VA	0.14 (5/35)	1.00 (251/251)	**1.00 (5/5)**	0.89 (251/281)
Near VA ≥0.3 binocular (logMAR)	0.26 (9/35)	0.88 (221/251)	0.23 (9/39)	0.89 (221/247)
Abnormal Plusoptix[‡]	**0.31 (11/35)**	0.98 (246/251)	0.69 (11/16)	0.91 (246/270)
Lang II Test >400’’	0.26 (9/35)	0.94 (235/251)	0.35 (9/25)	0.90 (235/261)
Combining two measurements				
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular	0.11 (4/35)	0.99 (248/251)	0.57 (4/7)	0.89 (248/279)
Distance VA ≥0.3 worse eye & Lang II Test >400’’	**0.20 (7/35)**	1.00 (250/251)	0.88 (7/8)	0.90 (250/278)
Distance VA ≥0.3 worse eye & Abnormal Plusoptix[*]	**0.17 (6/35)**	1.00 (251/251)	**1.00 (6/6)**	0.90 (251/280)
Near VA ≥0.3 binocular logMAR & Lang II Test >400’’	0.11 (4/35)	0.98 (246/251)	0.44 (4/9)	0.89 (246/277)
Near VA ≥0.3 binocular logMAR & Abnormal Plusoptix[*]	0.02 (1/35)	1.00 (251/251)	1.00 (1/1)	0.88 (251/285)
Lang II Test >400’’ & Abnormal Plusoptix[*]	0.09 (3/35)	1.00 (251/251)	**1.00 (3/3)**	0.89 (251/283)
Combining three measurements				
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular & Lang II Test >400’’	0.06 (2/35)	1.00 (250/251)	0.67 (2/3)	0.88 (250/283)
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular & Abnormal Plusoptix[*]	0.03 (1/35)	1.00 (251/251)	1.00 (1/1)	0.88 (251/285)
Distance VA ≥0.3 worse eye & Lang II Test >400’’ & Abnormal Plusoptix[*]	0.06 (2/35)	1.00 (251/251)	1.00 (2/2)	0.88 (251/284)
Near VA ≥0.3 binocular & Lang II Test >400’’ & Abnormal Plusoptix[*]	0 (0/35)	1.00 (251/251)	0 (0/0)	0.88 (251/286)
Combining all four measurements				
Distance VA ≥0.3 worse eye & Near VA ≥0.3 binocular & Lang II Test >400’’ & Abnormal Plusoptix[*]	0 (0/35)	1.00 (251/251)	0 (0/0)	0.88 (251/286)

VA = Visual Acuity (logMAR)
[*] Hyperopia >+4.00 D, Myopia < -2.00 D, Astigmatism ≤ -1.75 D or anisometropia >1.25

Supplementary II

Sensitivity and specifivity of screening method calculated using ROC curves (III):

Measurement	Threshold	Sensitivity	Specificity
Worst-seeing eye, screening (logMAR)	-0.05	93%	51%
	0.05	83%	73%
	0.15	67%	92%
	0.25	47%	98%
Most hyperopic eye, Plusoptix (all ≥0 dioptres)	+0.38	92%	11%
	+0.88	80%	36%
	+1.13	76%	50%
	+1.63	60%	77%
	+1.88	52%	84%
	+2.38	44%	94%
Most myopic eye, Plusoptix (all ≤0 dioptres)	-0.38	80%	78%
	-0.38	80%	78%
	-0.63	60%	87%
	-1.00	40%	91%
Most astigmatic eye, Plusoptix (all ≤0 dioptres)	-0.13	100%	1%
	-0.38	89%	36%
	-0.63	61%	68%
	-0.88	43%	83%
	-1.38	36%	95%
Anisometropia, Plusoptix (dioptres)	0.13	79%	29%
	0.38	46%	71%
	1.13	21%	98%
Interocular difference, screening	0.5 lines	60%	78%
	1 line	50%	78%
	2 lines	30%	97%

Supplementary III

Estimated cost of the new vision screening method for preschool children for the first and second year for best- and worst-case scenario.

Subject	Price	Total in DKK
BEST-CASE SCENARIO		
Salary for optometrist	250 DKK/hour (7 hours/day; 24 days)	42,000
Visual Acuity charts	500 DKK/chart (one-time expense, five stores)	2,500
Plusoptix	50.000 DKK (one-time expense, five stores)	250,000
Accommodation (abroad)	1.000 DKK/day, 16 days	16,000
Daily allowance (abroad)	300 DKK/day, 16 days	4,800
Total for the fist year		**315,300**
Price per child	**For 800 children**	**395**
Total for the second year		**62,800**
Price per child, second year	**For 800 children**	**79**
WORST-CASE SCENARIO		
Salary for optometrist (+25%)	250 DKK/hour (7 hours/day; 30 days)	52,500
Accommodation (abroad) (+20%)	1.000 DKK/day, 20 days	20,000
Daily allowance (abroad) (+20%)	300 DKK/day, 20 days	6,000
Total for the second year		**78,500**
Price per child, second year	**For 800 children**	**98**