A Review of Vision Screening Techniques for School-aged Children

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Regular vision screening in children is necessary for identifying potential eye problems early. Existing studies primarily assess one or two vision screening techniques, but few reviews have compared all available techniques, and none have sought to identify the most valuable for scaling in low-resource schools. In this review, we aim to summarize the primary vision screening methods for school-aged children. In general, vision screening methods can be divided into four categories: eye chart-based assessment, retinoscopy assessment, instrument-based autorefraction, and portable photorefraction assessment (photoscreeners). We highlight the working principles, technical details, advantages, and limitations of each technology and summarize their quantitative performance metrics. We suggest that photoscreeners achieve a good balance between measurement accuracy, screening cost, and convenience especially in service of children in at risk populations. We also explore possible directions for the vision screening techniques of the future.

Keywords: Biomedical Engineering, Biomedical Devices, Biomedical imaging, Vision screening, Pediatric myopi

1 Introduction

Visual function affects quality of life and plays an extremely important role in childrens physical, cognitive and social development. Approximately 80% of learning is processed through the eyes during the first 12 years of a child's life1. In the United States, around 6.8% of children under 18 have been diagnosed with an eye condition [1], and nearly 3% of children have vision impairment or blindness [2]. Vision problems of childhood may continue to affect health and well- being through adulthood, leading to social exclusion in recreational activities as well as reduced participation in the workforce [3,4]. Because this issue affects so many children, a review of different vision screening techniques will provide valuable assistance to school officials and health advocates. Of particular concern is the importance of identifying the optimal vision screening method for lower income communities, as low income children are nearly twice as likely to have vision difficulties as children in higher income communities while also facing greater barriers to vision care including transportation and scheduling challenges [5]. According to a 2016 study by the National Center for Childrens Vision and Eye Health, the financial burden of vision disorders in children is also considerable, and already reaches 10 billion dollars per year in the US alone [6].

Refractive errors are the most common vision problems that occur in childhood. They significantly impact daily life and have emerged as major public health concerns worldwide [7]. Refractive errors of the eye keep light from focusing correctly on the retina, resulting in blurred vision. The main causes of refractive errors in children consist of myopia (nearsightedness), hyperopia (farsightedness) and astigmatism [7]. Significant refractive error can also be associated with other eye disorders such as amblyopia (lazy eye) or strabismus (crossed eyes) [8]. The World Health Organization estimates that of the approximately 19 million children and adolescents between the age of 5 to 15 years who suffer from visual impairment, around 67% experience impairment as a result of uncorrected refractive error [9]. Fortunately, most refractive errors can be easily corrected with glasses, contact lenses, or refractive surgery [10].

If children are not aware of their vision issues themselves, it may be hard for others to notice the problems at an early stage [11]. When vision issues occur, most children dont complain about it and simply adjust to the poor vision by moving objects closer or avoiding activities that require visual concentration [12]. Proper vision screening methods and strategies can help minimize the social and personal damage caused by uncorrected refractive errors.

Vision screening can be conducted by school nurses, primary care doctors or optometrists. The process typically consists of a visual acuity test, autorefraction test, eye alignment test, and eye health exam [13]. Vision screening can detect basic vision issues and identify children at high risk for eye problems, but it won't diagnose the exact problem. Once vision issues are identified, children at high risk will be suggested to go to a medical specialist for further vision correction or treatment [14]. The early detection of vision disorders in children ensures timely and effective intervention, which prevents further visual impairment and complication however, vision screening techniques vary in effectiveness and accessibility and have unique tradeoffs in their application. Therefore, there is an urgent need for large-scale vision screening methods that can accurately assess refractive errors in school-aged children.

Quantitative performance metrics such as sensitivity, specificity, positive predictive value (PPV, the likelihood that a positive test correctly identifies a patient with the condition), and negative predictive value (NPV, the likelihood that a negative test correctly identifies a patient without the condition) are crucial in evaluating the effectiveness of vision screening programs[15]. The sensitivity and specificity of a screening test share an inverse relationship. Highly sensitive tests may produce more false positives and lead to unnecessary referrals and healthcare costs, while highly specific tests could miss vision impairment cases[15,16]. In community screening programs, selecting referral cut-offs requires balancing these two factors to achieve the optimal combination for their specific objectives[16].

The vision screening requirements for children vary by state[17]. Though about 80% of US states require vision screening for school-aged children, mandates differ regarding the ages when children undergo screening and the types of screenings conducted[18]. In addition, health disparities and inequities also exist in vision health care. There are notable disparities in vision assessment rates among different student groups based on household income, education level, insurance coverage, and ethnicity. Children from socioeconomically disadvantaged backgrounds were found to be less likely to receive vision testing in a clinical setting[19]. Therefore, to achieve equity in eye health, it is important to expand the high-quality vision screening services to all children in need. For example, in 2016, Massachusetts mobilized photo screeners and trained professionals in public and private preschool districts[6].

Current vision screening approaches can be divided into four categories: vision chart-based subjective assessment, objective retinoscopy assessment, instrument-based autorefraction assessment and portable photorefraction assessment. This review seeks to summarize the main vision screening methods and techniques, describe how each method operates, and explore their technical differences, advantages, and limitations. This comparison will assist researchers, medical practitioners, and school administrators who are interested in the current state of the field of vision screening.

2 Methods

Peer reviewed publications were identified using Google Scholar and PubMed. These tools were selected to find the widest possible range of possible papers to include. The inclusion criteria for this review were English language peer-reviewed articles related to vision screening for school-aged children which included discussion of vision screening methods or techniques. Both research papers and review articles were included. First, a general search was conducted using the following keyword search strings: vision screening techniques children, visual acuity screening test in school, instrument screening methods. We used the Joanna Briggs Institutes (JBI)JBI critical appraisal checklists to evaluate the quality of the articles for inclusion in our study and present them as a PRISMA-inspired flow diagram (Figure 1)[20]. These include criteria for qualitative studies such as congruity between the research methodology and the research question and that the conclusions are adequately drawn from the analysis, or interpretation, of the data. Separate JBI checklists were consulted for reviews and case series. The 20 most relevant articles identified by this search were screened for inclusion and two were removed due to conflicts of interest Additional references were identified and analyzed by manually reviewing the citations in the articles obtained during the initial round of retrieval. Then, a second round of literature search was conducted for each vision screening method identified in the first round of search results. The search terms involved for specific vision screening methods were eye chart screening, retinoscopy screening, retinoscopy, autorefractor, photorefraction, and photoscreener. The search results by each keyword were sorted by relevance or best match, and 16 articles published after 2000 that met the JBI criteria were identified, leading to 34 total articles. The oldest article was published in 2001[21] and the most recent in 2023[22]. The articles had an international scope, including research articles from India[23], Nepal[24], Turkey[25], Canada[26], the United States[16], and the United Kingdom[27]. Sample sizes in the research studies varied from 42[23] to over 2000[16]. The children screened in the studies ranged from two years of age to eighteen years of age with mean ages from 5[27] to 11[24]. These research studies were not randomized controlled trials, although several did compare the performance metrics for the screening method of interest to established methods such as retinoscopy[24,25]. The lack of randomized controlled trials in this field is a limitation, as is the small sample size for some of the articles[23,24].

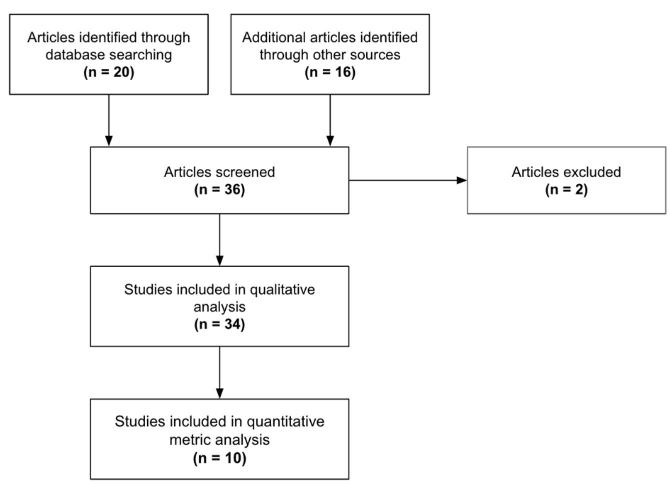

Fig. 1 Adapted PRISMA flowchart for this systematic review.

3 Results

3.1 Vision Chart-based Screening

The most traditional method of measuring visual acuity for children entails having the patient read a standardized eye chart at a certain distance29 (Figure 2). This type of vision screening method is also called optotype-based screening. The vision test chart design can come in various forms such as letters, numbers or symbols30. The patient covers one eye and reads out the lines they can see on the chart. Visual acuity is determined by the smallest object visible to the patient.31 Vision chart-based screening can also provide information about the presence of refractive error.

The Snellen eye chart, introduced in 1862 by the Dutch ophthalmologist Hermann Snellen, is the most common and most recognizable test chart32. The Snellen chart became the first state-supported vision screening program in a school setting in 189933. It includes 11 rows of capital letters. Each row has increasing numbers of letters in smaller sizes. The result of the visual acuity test using a Snellen eye chart or other test chart is expressed as a fraction. The numerator is the test distance between the patient and the chart (20 feet) and the denominator describes the distance at which a person with normal vision could read the same line on the chart. Hence 20/20 represents perfect eyesight.

Vision chart based methods have the advantage of being generally quick and affordable, which makes them suitable for employment in places where screeners have limited time and resources. However, these methods also have several drawbacks. One study from our review tested the Snellen optotype chart in children in the United Kingdom and observed a high percentage of false positives[27]. The authors also explain that students who receive false negative results are often not re-screened and so the total number of such cases are unknown[27]. In addition, the visual acuity assessment method is designed primarily to detect myopia and is therefore less effective at identifying other eye issues such as hyperopia, astigmatism or amblyopia[23]. It is also important for the patient to maintain their attention during the test or the measurement results will become less accurate. Finally, because this assessment method relies on self-reporting, cheating can occur, which may lead to incorrect assumptions about a patients true visual acuity[28,29].

3.2 Objective Retinoscopy Screening

Retinoscopy is considered the gold standard for determining refractive errors of the eye in children25. This method requires the use of a handheld instrument called a retinoscope to evaluate the refractive state of the eye. The retinoscope works on Foucaults principle, projecting diverging rays of light into the eye and observing the movement pattern of fundus reflex (the reflection of light from the back of the eye thats visible in the pupil, also known as red reflex) compared to the incident beam[30] (Figure 3). For an eye with refractive errors, the light reflex in the pupil either moves with or against the movement direction of the incident beam shining to the eye. Eye doctors can perform the objective measurement of the refractive error by adding proper minus or plus lenses to neutralize the light reflex in the pupil[31]. Retinoscopy is often conducted with cycloplegia eye drops that temporarily paralyze the ciliary muscles of the eye for more accurate results[32].

Fig. 2 Eye chart-based vision screening depicting a Snellen chart (image created using DALL E 3)

Retinoscopy screening for vision problems of children is very common in clinical practices today and can provide more accurate screening results than vision-chart based screening as measured by percent sensitivity[16]. Retinoscopy doesnt require the subjective feedback from children to conduct the measurements, and avoids the errors caused by miscommunication between the patient and doctor and possible cheating. Retinoscopy is especially suitable for the screening of younger children who may not cooperate with the subjective refraction examinations[33]. In addition, unlike vision-chart based screening, retinoscopy can detect hyperopia and astigmatism, even when visual acuity is normal[23]. However, retinoscopy does have its own limitations. It requires advanced clinical ophthalmic training for the healthcare professionals to perform such a test. Thus, retinoscopy may not be suitable for inexperienced nonclinical personnel such as school nurses or teachers[23].

3.3 Instrument-based Autorefraction techniques

Technological developments in the past few decades have greatly improved the efficiency, accuracy and patient comfort of vision exams[34,35]. Autorefraction techniques were developed to automate the process of manual refraction with the help of advanced medical instruments. They can offer many advantages over the traditional time-consuming refractive measurement. For example, autorefractors can provide reliable automated objective assessment of refraction in a patients eye, allow clinical assis-

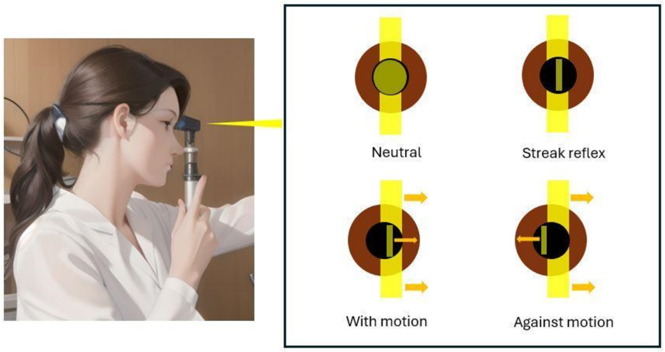

Fig. 3 Retinoscopy based vision screening and retinoscopic reflex (image created using DALL E 3)

tants to perform autorefraction, and greatly reduce the workload of eye doctors[36].

The design of autorefractors varies based on their underlying principles. The basic components of autorefractor design include an infrared source, a fixation target and a Badel optometer[37]. Early objective autorefractors such as Dioptron autorefractor (Coopervision) operate based on the image quality analysis principle[38]. This type of autorefractor instruments often associated with several limitations as alignment difficulties, accommodation challenges, and irregular astigmatism[39]. The design, speed, and sensitivity/specificity of autorefractors have been further improved with advancements in modern technology. Most modern autorefractors are based on the Scheiner principle, which provides a simple method to determine the level of ametropia. In this type of autorefractor, a double pinhole aperture is placed in front of the pupil, and the two pinholes images will coincide for the emmetropic eye and separate for the eye with refractive errors[39]. The different positions of the pinholes viewed by the patient can be used to differentiate the case of myopia or hyperopia. The separation distance of the pinhole images is linearly related to the refractive error. The Scheiner principle provides a direct evaluation of the eye's focusing ability. This method offers a clear distinction between different types of refractive errors. Many modern autorefractors that use the Scheiner principle can automatically adjust and calibrate based on the detected focus, ensuring consistent measurements[40]. However, other principles have been shown to be more effective in certain circumstances. For example, in a comparison of six autorefractors, the two autorefractor that had the best precision and accuracy used the wavefront and retinal image size principle[41].

The newest autorefractors implement the Scheiner principle in a slightly modified fashion, whereby Scheiner double pinhole apertures are replaced with two LEDs as the imaging sources[36], as shown in Figure 4. A dual photodetector is used to capture light coming out of the eye. As the LEDs are moved back and forth, the refractive state of the eye can be calculated by analyzing the LED position[37]. Typical autorefractor products based on this principle include the Nidek AR series, Nikon NRK series, and the Shin-Nippon NVision series. Commercial autorefractors are available in the form of either table-top or handheld. In the articles reviewed, table-top autorefractors were found to offer better control over fixation and accommodation. In comparison, handheld autorefractors such as Retinomax (Visionix) and Sure-Sight (Welch Allyn) have advantages of ease of alignment and portability[13,34].

One significant disadvantage of most tabletop autorefractors is their relatively large size and the requirement that they be mounted on a table for operation. This limitation impacts their usability in various settings, particularly in mobile clinics, outreach programs, and non-clinical environments such as schools or rural areas. A 2018 review paper that we included in our analysis notes that autorefractors have a relatively short working distance and require separate monocular measurement, which is challenging in the case of very young children[34]. By employing a simplified approach to wavefront sensing, the handheld autorefractor eliminates the need for moving parts and costly components. Its open-view design proves more effective than the auto-fogging mechanism of conventional tabletop autorefractors in reducing the effects of accommodation[34]. However, even the handheld autorefractors have their own drawbacks. The 2005 study on 75 children in Mexico from our review identified a tendency for the leading Retinomax autorefractor to underestimate hyperopia in children[42].

However, several unique challenges arise when performing autorefractor tests on children. To obtain accurate readings, children need to stay still, their head should be aligned properly, and their gaze should be fixed on the target throughout the test[43]. Most autorefractors test one eye at a time, which limits their ability to detect strabismus in the absence of abnormal refractive error[34]. Due to the complexity and size of instruments, especially the tabletop autorefractors, autorefractors are primarily deployed in a clinical setting and operated by healthcare professionals for vision screenings[44]. In addition, the high cost of autorefractors limit their potential applicability for large-scale vision screening programs[45].

3.4 Portable photography-based refraction techniques

The photography-based refraction technique was first introduced in the 1970s and has been considerably improved over the years[46,47]. Vision screening products based on this technique are conventionally named Photoscreeners. Photography-based refraction involves the process of interpreting photos of the eye to screen for vision defects associated with various ocular structural disorders[21]. Eccentric photorefraction is the most used optical design among photoscreeners today[48].

A photoscreener device is a portable device that looks like a

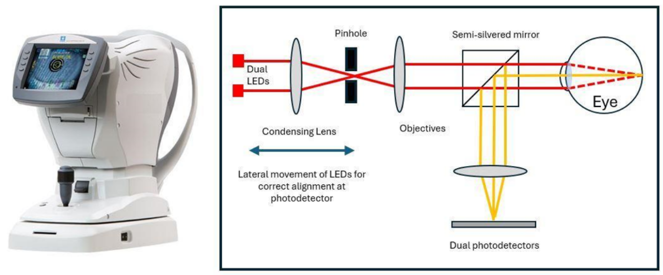

Fig. 4 Representative autorefractor alongside the working principle (image created using DALL E 3)

DSLR camera (Figure 5) Infrared light is used to avoid patient glare, and it can also keep the pupil size large without the need for dilation[49]. A fixation target and sounds are used to help keep a child's focus during screening. Many photoscreeners of this type induce the red reflex with a series of flashes. The refractive state of the eye will cause shape changes of the retinal reflex. For example, the pupil of an emmetropic eye will appear uniformly dark in the photographic image, while an ametropic eye will generate a crescent in the pupil. The retinal reflex on the pupil is captured by the camera behind the aperture. These images of the retinal reflex can be evaluated by eye doctors or trained staff using device integrated software[50]. Commercially available Photoscreener products include the Spot vision screener (Welch Allyn)[22,24], 2WIN model (Adaptica)[50], and the Plusoptix series (Plusoptix)[51].

Photoscreeners are effective tools for the early detection of refractive errors, amblyopia and strabismus[50]. Compared to autorefraction techniques, photoscreeners offer several advantages. Photoscreeners can also capture images of both eyes simultaneously, providing a more comprehensive view of refractive errors and other eye conditions. Additionally, because photoscreeners are often faster and less invasive than other methods, they require less precise alignment and a shorter testing time[52]. Due to the quicker and less skill-intensive nature of photoscreeners, the cost per test is lower than other device-based screening methods[53]. Many autorefraction instruments require a certain level of experience from operators and cooperation from the children being screened. In contrast, the simplicity of photoscreeners allows non-specialist staff or technicians to conduct screenings with minimal training[54]. However, some studies have shown that variability between operators could influence the reliability rate of photoscreeners, which should be taken into consideration[50]. For example, the kappa value for reliability of interpretation between observers was reported as 0.55, which indicates moderate agreement between the observers[55]. Additionally, two articles from our review found that photoscreeners tend to underestimate hyperopia and overestimate myopia[24,50].

With the features of relative portability, simplicity and quick results, photoscreeners could be well-suited for mass vision screenings in specific settings, such as rural schools or low-income urban areas, where access to high quality healthcare may be limited. For instance, the Lions Clubs International Foundation (LCIF) and its partners, have conducted free comprehensive vision screenings for 250,000 young children and primary school students, particularly in low-income communities[56]. These children were screened by volunteers equipped with handheld photoscreeners to identify common vision issues. Photoscreeners can play a critical role in bridging healthcare gaps and promoting early intervention for vision-related issues, especially among low-income students.

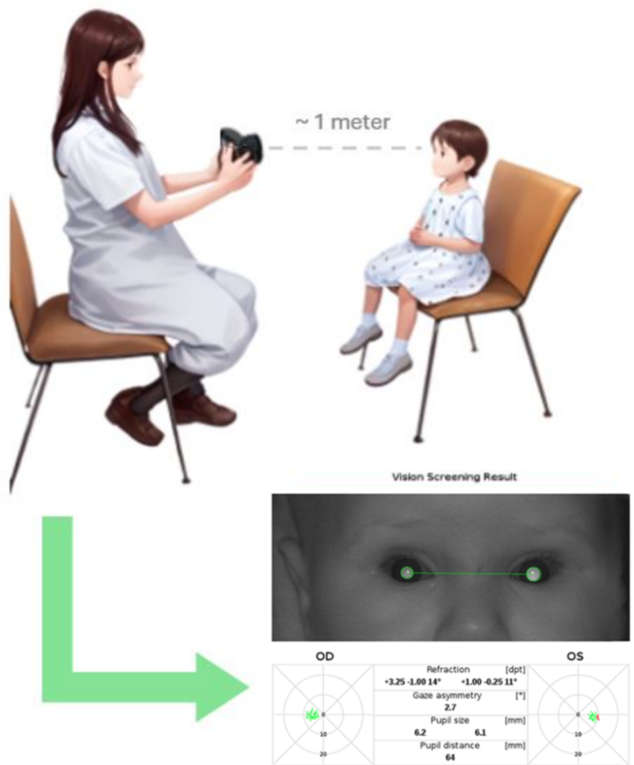

Fig. 5 Photoscreener based vision screening (sample vision screening result from Plusoptix photoscreener). (image created using DALL E 3)

Direct comparisons of screening performance metrics between the different vision screening techniques and products are challenging. The change in referral criteria has an influence on the accuracy metrics of vision screening. While some products follow the AAPOS guidelines, others utilize different alternative standards[22]. In addition, most photoscreening devices allow users to adjust the specificity and sensitivity criteria, depending on specific requirements of individual screening programs[16]. To address these concerns while providing a meaningful comparison of different screening methods, we identified 10 articles from the 34 included in our review that provided a percent sensitivity, specificity, PPV, or NPV for at least one screening method in use with children. We calculated an average of all values and present them with the lowest and highest value in the range in Table 1.

Vision charts (Snellen chart[27] and Cambridge Crowded Acuity Cards[26] performed the worst in average specificity (73%), PPV (38%), and NPV (83%), but outperformed the other categories in sensitivity (80%). Noncycloplegic retinoscopy performed best across specificity (97%), PPV (79%), and NPV (95%), with Autorefractors trailing closely. Photoscreeners (Plusoptix, Spot, and MTI) performed better than vision charts, but worse than the other two categories.

4 Discussion & Conclusion

In the vision screening field, greater preference is given to specificity and PPV, with the intention being to prioritize eliminating false positives over avoiding false negatives[34]. The risks of increased parental anxiety and loss of trust in vision screening are deemed greater than that of missing the mildest cases of amblyopia and other conditions[34]. By this criteria, Vision Charts perform particularly poorly. All four methods analyzed had higher NPV than PPV on average, but Retinoscopy performed the best in both specificity and PPV.

Our findings regarding the relative quantitative performance metrics of each vision screening method agree with those of the Vision in Preschoolers Group, whose 2005 analysis of various vision screeners found that noncycloplegic retinoscopy was the overall best test for the detection of amblyopia, significant refractive error, and other conditions[16]. Our analysis represents a unique contribution to the field because we are the first review to calculate averages for all four performance metrics across each type of vision screener. This will empower school administrators and other professionals to make informed decisions about which vision screening method is appropriate for their needs.

While we calculated an average for all vision screeners of a particular type, the performance of individual devices varied somewhat within each category. For example, Nishimura et al., found that the Plusoptix S12 photoscreener had an average sensitivity of 64%, specificity of 88%, PPV of 65%, and NPV of 87% while the Spot photoscreener had an average sensitivity of 60%, specificity of 93%, PPV of 76%, and NPV of 86% 26. It is also worth noting that Photoscreeners in particular performed better for some vision screening tests than others. For example, a 2001 review included in our analysis found that the Medical Technology Innovations (MTI) photoscreener had 95-100% sensitivity for strabismus, but only 20-80% sensitivity for hyperopia[21].

One limitation in our calculation of performance metrics is that none of the studies in our analysis compared all four categories of vision screeners in the same patient population. The differences in study design, patient populations, and the data quality in various literatures also may have contributed to the variation in the screening performance of different techniques and instruments. Further research that compares all four vision screening methods in a single study would be valuable.

While retinoscopy and autorefractors outperformed photoscreeners in several metrics, they have considerable downsides in implementation. They either depend on the childs understanding and cooperation or require a considerable amount of time and experience for the examiner[24]. In comparison, the photoscreener method allows quick and objective comprehensive measurements of the eye by non experts and can provide a more time-efficient and cost-effective approach for vision screening[24,50,54]. These advantages make photoscreeners suitable for mass vision screening programs that do not have access to the resources required to implement retinoscopy or autorefractor screenings, especially those conducted in school or community settings. Programs considering photoscreeners must consider that these devices are only semi-automated, still requiring manual operations from the examiner at times[24]. Research has shown that training the examiner greatly increases the reliability of photoscreeners, with some estimating that operators should perform 100 tests to achieve adequate experience[50].

The development of a truly automated vision screener, with self-service objective vision measurements and built-in intelligent patient case management software would benefit future large-scale vision screening programs in rural schools or other areas with limited access to healthcare. Such a device would also reduce variability due to differences in operator training and performance. However, fully automated vision screeners will need to demonstrate sufficient accuracy.

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Table 1 Quantitative performance metrics of each pediatric vision screening method

Method	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Vision Chart	80 (51–100)[26,27]	73 (69–76)[27]	38 (32–50)[26,27]	83 (79–86)[27]
Retinoscopy	75 (38–100)[16,23,32]	97 (93–99)[42]	79 (44–94)[42]	95 (83–100)[23,42]
Autorefractors	63 (35–100)[16,25,42]	92 (83–100)[25,34,42]	72 (40–100)[25,42]	91 (76–100)[25,42]
Photoscreeners	75 (24–100)[16,22,25,26,50]	75 (59–91)[22,25,26,50]	74 (48–97)[25,26,50]	84 (62–100)[25,26,50]

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