

# Pre-Cycloplegic Exam Benefit of Photoscreening and Accommodation-Relaxing Skiascopy

Jacob David Schaafsma<sup>1</sup>, Robert W Arnold<sup>2</sup>

<sup>1</sup>School of Medicine, University of Milan, Milan, Italy; <sup>2</sup>Alaska Blind Child Discovery, Alaska Children's EYE & Strabismus, Anchorage, AK, USA

Correspondence: Robert W Arnold, Alaska Blind Child Discovery, Alaska Children's EYE & Strabismus, 3500 Latouche Street #280, Anchorage, AK, 99508, USA, Tel +1(907)561-1917, Fax +1(907)563-5373, Email [eyedoc@alaska.net](mailto:eyedoc@alaska.net)



**Background:** Seeking a quick way to estimate refractions for challenging pediatric patients, we studied two non-contact methods with particular attention to accuracy and level of stress in uncovering cycloplegic hyperopia.

**Methods:** Newly referred and follow-up pediatric eye patients had timed school bus accommodation-relaxing skiascopy (SBARS) and Plusoptix A12 (Px) photoscreener testing before cyclopentolate 1% confirmatory examinations. The ABCD ellipsoid univariate method based on relative blur and vector components was used to compare dry sphero-cylinder refraction estimates with cycloplegic. Receiver operating characteristic (ROC) curves were used to determine screening value.

**Results:** Three compared refractions were attempted in 191 racially diverse children of whom 100 were age 0.2–3.9 years and 91 were 4 to 14 years. Plusoptix failed to yield a result in 21 and an additional 21 were interpreted as an excess sphere. Median spherical equivalent did not differ between Px and SBARS for 149 with Px readings but in hyperopic patients, Plusoptix uncovered 27% less hyperopia. The ellipsoid for SBARS of 0.8 was better than 2.4 for Plusoptix (Mann–Whitney  $p < 0.001$ ). Plusoptix was fastest (3–15 seconds) followed by SBARS (15–30 seconds) compared to 30–45 minutes for cycloplegic exam.

**Conclusion:** Non-contact quick refractive methods enhanced confirmatory cycloplegic pediatric exam in high-risk pediatric patients.

**Keywords:** sphero-cylinder, refraction, autorefraction, photoscreening, developmental delay

## Introduction

Refraction in the pediatric eye examination is critically important but can be difficult, stressful and slow.<sup>1</sup> Perhaps, some modern screening techniques could be useful as a part of a confirmatory pediatric eye examination. Two non-contact techniques that can be useful in community screening for amblyopia could also be utilized as an early aspect of a confirmatory eye examination. They are dry retinoscopy and infrared multi-radial photoscreening. Dr David Silbert, who also continues to value the advantages of photoscreening as a component of pediatric eye exams, tried to answer whether a leading photoscreener could replace cycloplegic examination.<sup>2</sup> A question remains: How useful are these non-contact techniques in the eye exam of high-risk pediatric patients?

Retinoscopy with or without enhancements such as dynamic retinoscopy or skiascopy can serve as a helpful vision screening tool. Eibschitz proved localized community amblyopia reduction when a group of plus-3 retinoscopy-screened children then treated were compared to a local, age-matched community cohort.<sup>3</sup> The NIH-sponsored phase-1 of the Vision in Preschoolers (VIPS) study evaluated experienced-optometrist-retinoscopy (non-cycloplegic retinoscopy) which out-performed early photoscreeners, hand-held autorefractors and visual acuity in terms of sensitivity to detect amblyopia risk factors.<sup>4</sup> Dynamic retinoscopy has value in estimating accommodative reserve or compromise as a risk for amblyopia in children who can thus cooperate.<sup>5</sup> The dynamic response to skiametry further enhances the evaluation of hyperopia and latent hyperopia.<sup>6</sup>

Photoscreening employs pupillary red reflex evaluation with a nearly coaxial light source such that crescents of light appear as a function of refractive error in various meridia.<sup>7,8</sup> More than two decades ago, photoscreening was practically employed by Angi and Freedman to detect amblyopia.<sup>9,10</sup>

Hyperopia in one or more meridia, in one or both eyes, is a predominant amblyopia risk factor.<sup>11</sup> Moderate hyperopia detected during cycloplegic retinoscopy is common and normal in most young children. On the other hand, excess hyperopia for which accommodation is not sufficient can cause refractive amblyopia, or if accommodation is excessive can cause accommodative esotropia leading to strabismic amblyopia. The type of fixation target on a photoscreener can regulate the degree of accommodation and uncover higher degrees of potentially amblyopiogenic, latent hyperopia.<sup>12</sup>

Photoscreeners are designed to be used in the pediatric medical home, or community outreach, to uncover children with excess amblyopia risk factors. We studied how photoscreeners can also have a helpful role used in the pediatric ophthalmologist office providing refractive and ocular alignment estimates before and after cycloplegia.

Self-adjusted spherical spectacles have value in predicting refraction, however they can underestimate hyperopia due to allowed accommodation.<sup>13</sup> In fact, visual acuity by dry automated refraction outperformed cycloplegic visual acuity in this recent study.

Spectacle prescriptions can be mathematically compared. The gold-standard method involves converting the three spherocylinder components sphere, cylinder magnitude and cylinder axis via vector transformation into a spherical equivalent and the two J0 and J45 components.<sup>14</sup> These two J0 and J45 vectors can then be further converted 3-dimensionally and compared on the basis of relative spectacle blur and age to derive an “ellipsoid” univariate metric for spectacle comparison.<sup>15</sup> Using the ellipsoid method, a smaller value of 1.0 or less indicates that the candidate spectacle will yield visual acuity within one logMAR line of the ideal target spectacle.<sup>15</sup> An ellipsoid value of 2.0 means the candidate spectacle yields visual acuity blur of 3 lines from ideal target and an ellipsoid value of 3.0 or more yields a visual acuity blur within 6 or more logMAR lines.<sup>16</sup>

Reducing or blocking accommodation has been needed to reveal the actual amount of hyperopia. Cycloplegia is the gold-standard method for reducing accommodation. However, there are practical difficulties with cycloplegia including pain and stress with the eye drops, wash-out due to reflex lacrimation and imperfect absorption of the drop. Another method for reducing accommodation is fogging by placing a higher plus lens over the non-retinoscoped eye.<sup>17</sup> If a rack of plus lenses are held vertically over the retinoscoped eye, hyperopia may be missed.<sup>18</sup> On the other hand, a specially crafted plus lens rack held horizontally over both eyes has the potential to uncover much more hyperopia even without cycloplegia as long as the child is willing to participate.<sup>19</sup>

## Methods

This prospective evaluation of screening tests is undertaken by the Alaska Blind Child Discovery research project and complies with the Declaration of Helsinki and the Health Insurance Portability and Accessibility Act (HIPAA) with Institutional Review by Providence Alaska Medical Center. Parents and/or guardians gave written informed consent and patients with developmental age older than 13 years also gave written assent. De-identified data can be retrieved from <https://www.abcd-vision.org/references/SBARS%20PX%20De-ID%202023.pdf>.

New patients referred by pediatric and community photoscreening and therefore at high risk for amblyopic refractive error and follow-up pediatric ophthalmology patients already accustomed to spectacles were recruited for this study. At the onset of the examination, before any cycloplegia, experienced staff performed Plusoptix A12 (Px) photoscreening and also estimated refractive error using the school bus accommodation-relaxing skiascopy (SBARS: Eye Care and Cure – Hilco, Phoenix, Az;) technique. A Plusoptix A12 (software version 7.2.5.0) remote autorefractometer was attempted on all patients. The Plusoptix manufacturer suggests a capability to estimate refractions between  $-7$  D and  $+5$  D. When the device interprets excess myopia sphere or cylinder, it reports “MYO” and for excess spherical or cylinder hyperopia reports “HYP”. For numeric calculations, we substituted a refractive value of  $-7.00$  sphere for all reports of “MYO” and a value of  $+5.00$  sphere for all reports of “HYP”. When the Plusoptix was unable to give an estimate due to small or indeterminate pupils, or fixation loss or constant strabismus, those cases were analyzed as a “Plusoptix No-Read”.

Then, the remainder of the confirmatory examination was performed including age-appropriate estimation of visual acuity and ocular motility before 1% cyclopentolate cycloplegia. To numerically account for visual acuity in young

children, we employed a fixation-based logMAR estimate.<sup>20</sup> Thirty minutes later the exam was completed with cycloplegic retinoscopy which was then refined at the phoropter in cooperative patients and finally the ocular media and retinae were examined. Determination of any prior refraction and review of chart history was completed after the initial Plusoptix photoscreening and dry SBARS retinoscopy. Data were collected on patient age, gender, race/ethnicity and whether a developmental delay was present.

Patient cooperation with pediatric refraction and eye examination can be very challenging. The level of patient cooperation during SBARS and Plusoptix was defined as follows: good – gazes through lenses or at photoscreener for several seconds each higher plus, fair – will briefly glance and allow some increase in plus but still might be crying or upset, and poor: too timid or crying and will not voluntarily gaze through SBARS lenses or at the photoscreener fixation target. The times to estimate and then confirm refractive error were measured. Level of cooperation and time for exam are presented in Table 1.

## Sample Size Calculation

For mean value refractive error of 1.0 and standard deviation of 2.0, the alpha of 5% and power of 0.8, the sample size to detect a 0.25 diopter difference is 63. If only about 1/3 have good cooperation and have readings on Plusoptix, then at least three times 63 or 189 patients is needed.

## Spectacle Refraction Comparison

A single numeric grade for matching two spectacles relative to achievable visual acuity and age-appropriate accommodation called the ABCD Ellipsoid was used to determine how well each dry (before cycloplegia) refraction estimation technique (SBARS and Plusoptix) compared with the immediately subsequent, same-day, same-hour cycloplegic retinoscopy with phoropter refinement when possible. Cycloplegia was achieved with one drop of cyclopentolate 1% and waiting at least 30 minutes.

Seeking to assess the ability to uncover hyperopia, we defined refractive divisions in different ways depending on the comparison. Emmetropia for these children was defined between  $-1.00$  myopic and  $+0.75$  hyperopic cut-offs. Hyperopia was a spherical equivalent greater than or equal to  $+0.75$  and myopia was a spherical equivalent/lowest meridian less diopter power or equal to  $-1.00$ - magnitude of myopic meridian equal to or more than 1 diopter. To increase the cohort, “all hyperopia” of all patients expected to require some accommodation for distance and near viewing, patients were defined as those with cycloplegic spherical equivalent greater to 0.0 D. We defined those patients with astigmatism as a magnitude of astigmatism greater than or equal to 1.50 diopters.

## Amblyopia Risk Factor Screening

For vision screening performance of the SBARS and Plusoptix, we employed the age-based 2021 AAPOS Uniform amblyopia risk factor failure levels.<sup>11</sup>

**Table 1** The Level of Cooperation and Time to Perform Refractions Comparing Cyclopentolate 1% Cycloplegia (Drops) with Two Non-Contact Estimates, School Bus Accommodation Relaxing Skiascopy (SBARS) and Plusoptix A12 Photoscreening

Level	SBARS	Plusoptix	#	Cycloplegic	# Drops
“Good”	Gazes through convex lenses moved horizontally in front of eyes	Gazes at photoscreener fixation target several seconds	95	No cry, blinks	30
“Fair”	Briefly glances through a few lenses, might be upset	Brief glance at photoscreener, might be upset	77	Excess epiphora, blinks and looks away	48
“Poor”	Too timid or crying and avoid looking through lenses	WILL not gaze at photoscreener fixation target	19	Cries, shuts lids and resists further drops	113
Refract Time	20–30 seconds	3–15 seconds	191	30–45 minutes	191

**Note:** The number of patients is given under the heading #.

The normality of the data was assessed by Shapiro–Wilk test. When data was found to not be normally distributed, non-parametric tests (Mann–Whitney and Kruskal–Wallis) were employed. For proportions, Chi-square was used. Bland–Altman analysis following intra-class correlation was used to compare two tests applied to each identical, continuous data set.

## Results

Confirmatory eye examinations that included pre-cycloplegic photoscreening attempt and School Bus Accommodation Relaxing Skiascopy (SBARS) were performed on 191 children. In addition, infrared, multi-radial on-site interpreted photorefractive was done with a Plusoptix A12 before cycloplegia. Characteristics of the patients are summarized in Table 2. Ages ranged from 0.2 to 14.6 years with 100 under age 4 years and 91 children 4 years and older. There were 84 females and a racial/ethnic mix of 17 Black, 17 Alaska Native, 19 Hispanic White, 27 Pacific Islander, 31 Asian and 80 non-Hispanic White. There were 43 patients with developmental delay including 14 ex-premature, 13 with autism, 6 with Down or other syndromes, and 4 with structural central nervous system defects. Ninety-five were referred from photoscreening at their pediatrician's office visit or from school photoscreening clinics. Twenty-one had no reading from Plusoptix A12, while another 21 had excess values in at least one eye; 4 were interpreted as MYO for excessive myopia and 7 were HYP for excessive hyperopia right eye while for the left eye 2 were MYO and 15 were HYP interpreted excesses. For all patients right and left eyes, visual acuity median was 20/41 (IQR1 20/32, IQR3 20/41).

**Table 2** Patient Characteristics

Patient Characteristics	Aspect	#
Race/ethnicity:		
	Alaska Native	17
	Asian	31
	Black	17
	Hispanic, white	19
	Pacific Islander	27
	White, non-Hispanic	80
Delays:		
	Ex-premature	14
	Autism	13
	Down Syndrome	6
	CNS defects	4
Age:		
	Less than 4 years	100
	4–14 years	91
Gender:		
	Female/male	84/106
Photoscreen refer		95

**Note:** The number having various aspects under the heading #.

The level of cooperation with refractive estimates was poor in 19, fair in 77 and 113 cried and resisted with cycloplegia (Table 1). Cycloplegic examination took 30–45 minutes while SBARS took 20–30 seconds and Plusoptix 3–15 seconds to yield a sphero-cylinder refraction in both eyes.

## Spectacle Refraction Comparison

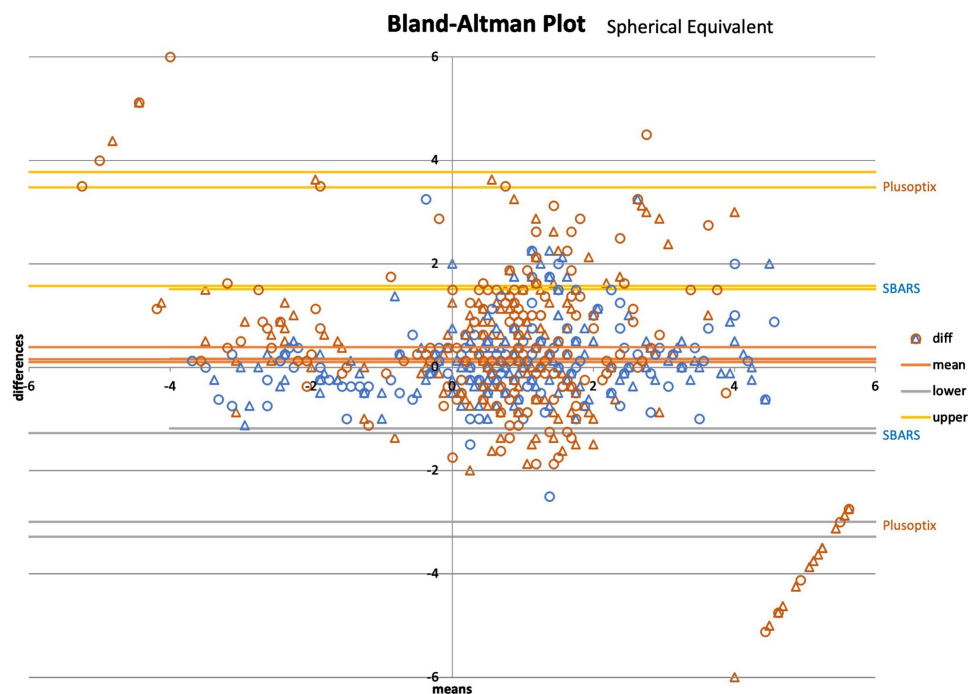
Table 3 shows values for spherical equivalent and for ellipsoid comparing candidate SBARS and Plusoptix refraction estimates and the target cycloplegic refractions. The distributions of ellipsoid and spherical equivalent for cycloplegic exams, for SBARS and for Plusoptix were found to not be normally distributed by Shapiro–Wilk test, therefore non-parametric analysis using medians and interquartile ranges (IQR1, IQR3), and Mann–Whitney and Kruskal–Wallis were used for comparative analysis. For all the 170 patients with Plusoptix readings, the spherical equivalent showed no difference between cycloplegic exam, Plusoptix and SBARS by Kruskal–Wallis for right eyes ( $X^2(2) = 5.6, p=0.06$ ) or for left eyes ( $X^2(2) = 3.1, p=0.21$ ).

Figure 1 shows Bland Altman analysis of spherical equivalent when candidates SBARS and Plusoptix targeted cycloplegic exam. For all patients with Plusoptix readings and any spherical equivalent hyperopic cycloplegic refraction >0D, the 130 median (IQR1, IQR3) right eye cycloplegic, Plusoptix and SBARS spherical equivalents were +1.37D (+0.75D, +2.25D), +1.00D (+0.37D, +1.88D) and +1.13D (+0.38D, +1.75D), respectively. The corresponding 132 left eye refractive values were cycloplegic +1.38D (+0.75D, +2.38D), Plusoptix +0.88D (+0.38D, +2.00D) and SBARS

**Table 3** Ellipsoids, Spherical Equivalents and Cylinder Predictions

Median (IQR1, IQR3)	n	Cohort	Target		Candidates		PlusoptiX	
			Cycloplegia		SBARS			
			Right Eye	Left Eye	Right Eye	Left Eye	Right Eye	Left Eye
Spherical Equivalent	191	All	1.38(0.75,2.25)	1.38(0.75,2.25)	1.13(0.63,1.75)	1.00(0.5,1.88)	21 no read	21 no read
Cylinder	191		0.75(0.25,1.5)	0.50(0.0, 1.50)	0.50(0.0, 1.50)	0.50(0.0,1.50)	21 no read	21 no read
Spherical Equivalent	170	Px read	1.00(0.16,1.84)	1.00(0.16,2.00)	0.88(0.0,1.50)	0.75(0.25,1.50)	0.63(−0.13,1.50)	0.63(0.0,1.59)
Cylinder	170	Px read	0.63(0.25,1.50)	0.50(0.19,1.50)	0.50(0.0,1.50)	0.50(0.0,1.50)	0.75(0.5,1.94)	0.75(0.25,1.75)
Spherical Equivalent	159	Px Rx	1.00(0.25,1.75)	1.00(0.25,2.00)	0.88(0.25,1.50)	0.75(0.25,1.50)	0.63(−0.13,1.50)	0.63(0.0,1.50)
Cylinder	159	Px Rx	0.50(0.25,1.50)	0.50(0.00,1.50)	0.50(0.00, 1.50)	0.50(0.00,1.50)	0.75(0.50,2.00)	0.75(0.25,1.50)
Spherical Equivalent	127	Hyperopia	1.38(0.75,2.25)	1.38(0.75,2.25)	1.13(0.63,1.75)	1.00(0.50,1.88)	1.00(0.38,1.94)	0.88(0.38,2.00)
Cylinder	127	Hyperopia	0.75(0.0,1.5)	0.50(0.0,1.50)	0.50(0.0,1.50)	0.75(0.0,1.50)	1.00(0.50,2.00)	0.75(0.25,1.75)
Ellipsoid	191	All	Target	Target	0.76(0.49,1.33)	0.71(0.48,1.19)	21 no read	21 no read
Ellipsoid	170	Px Read	Target	Target	0.77(0.50,1.32)	0.71(0.48,1.14)	1.84(1.17,2.98)	1.83(1.21,3.08)
Ellipsoid	159	Px Rx	Target	Target	0.75(0.50,1.24)	0.70(0.48,1.07)	1.73(1.10,2.69)	1.81(1.12,2.88)
Ellipsoid	127	Hyperopia	Target	Target	0.73(0.49,1.25)	0.69(0.46,1.06)	1.81(1.14,2.89)	1.83(1.26,3.07)
Ellipsoid match A	170	Px Read	Target	Target	63%	69%	20%	21%
Ellipsoid match A or B	170	Px Read	Target	Target	94%	93%	56%	56%
% predict hyperopia	127	Hyperopia	Target	Target	92%(71%,112%)	96%(62%,110%)	71%(19%,117%)	63%(27%,159%)
Over-minus >1D	170	Px Read	Target	Target	15 of 170	13 of 170	49 of 170	44 of 170

**Notes:** Data from compared refractive estimates school bus accommodation relaxing skiascopy (SBARS) and Plusoptix A12 (Px) targeting cycloplegic, refined retinoscopy with non-normally distributed data reported as medians in interquartile ranges (IQR1 and IQR3). The cohorts of (all) 191 pediatric patients include those 170 for whom Plusoptix was able to give an estimate (Px read) and the 159 for which Plusoptix gave a sphero-cylinder estimate (Px Rx). The ellipsoid with smaller values better is a univariate comparison between candidate and target refractions based on degree of blur. Included are performance to predict cycloplegic hyperopia and the percent with at least 1 diopter of over-minus estimate.



**Figure 1** Bland Altman analysis of spherical equivalent in diopters. Cycloplegic refraction is targeted by two dry techniques, school bus accommodation-relaxing skiascopy (SBARS) indicated in blue and Plusoptix A12 infrared photoscreener designated in Orange. Right eyes are designated with circles and left eyes are designated with triangles. The mean difference of both techniques approximates zero, but Plusoptix including 21 excess reading where  $-5$  was substituted for "MYO" and  $+5$  was substituted for "HYP".

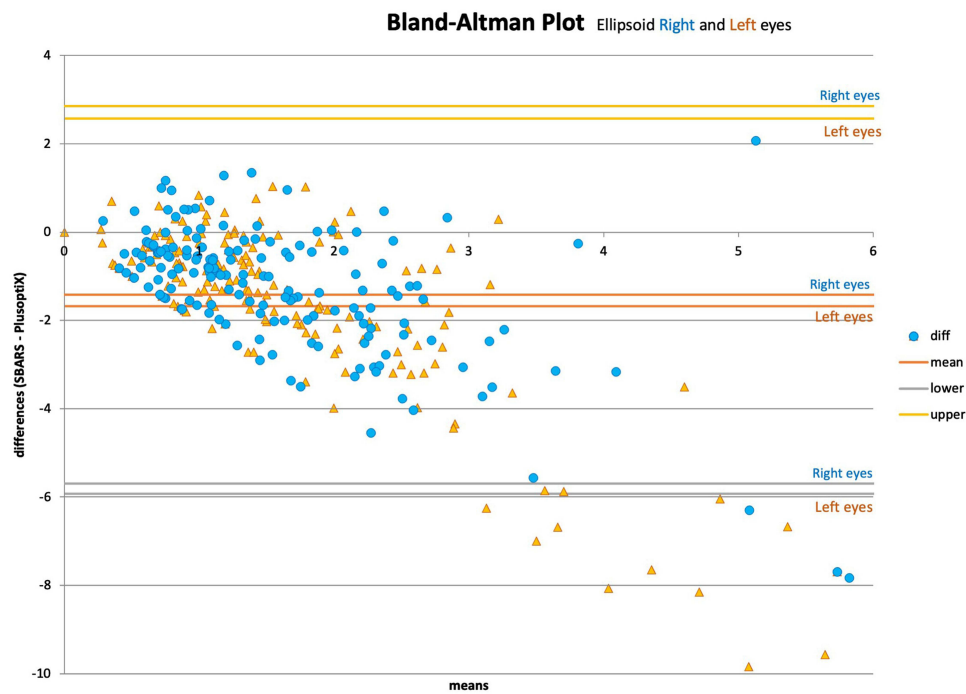
$+1.00D$  ( $+0.50D$ ,  $+2.00D$ ). The Plusoptix estimates accounted for a median 75% (IQR 19%, 150%) of the 130 true right eye cycloplegic hyperopia while SBARS accounted for 91% (IQR 67%, 111%). For the 132 hyperopic left eyes, Plusoptix accounted for 71% (IQR 17%, 125%) and SBARS 90% (IQR 63%, 108%).

The spherical equivalent for the 130 right eyes with SBARS median  $+1.06$  compared to Plusoptix  $+1.00$  (Mann–Whitney  $z=1.97$ ,  $p=0.5$ ) while the 132 hyperopic left eyes median SBARS  $+1.0$  did not differ from Plusoptix  $+0.88$  (Mann–Whitney  $z=1.06$ ,  $p=0.30$ ). The difference between cycloplegic refraction and the estimation techniques was evaluated for hyperopic cases: from 130 right eyes. SBARS median of  $0.90$  differed from the 130 right eye Plusoptix  $0.74$  (Mann–Whitney  $z=2.04$ ,  $p=0.4$ ), but for left eye the SBARS median of  $0.98$  did not differ from 132 left eye Plusoptix median of  $0.75$  (Mann–Whitney  $z=0.31$ ,  $p=0.760$ ).

For the Plusoptix refraction-capable and hyperopic patients, the percent predicted hyperopia comparing SBARS and Plusoptix targeting cycloplegic exam right eyes (91% vs 70%; Mann–Whitney  $z=2.6$ ,  $p=0.009$ ) and left eyes (96% vs 54%, Mann–Whitney  $z=1.7$ ,  $p=0.097$ ) showed unequal medians comparing both eyes (Kruskal–Wallis  $X^2(3) = 9.4$ ,  $p=0.025$ ). For the hyperopic patients with Plusoptix readings, over minus by more than 1 diopter 124 right eyes were 11% for SBARS and 31% for Plusoptix (Chi-square  $z=3.7$ ,  $p<0.001$ ) and for 117 left eyes 13% SBARS and 33% Plusoptix (Chi-square  $z=3.6$ ,  $p<0.001$ ). The visual acuity for patients who had a result with Plusoptix differed and was better than for children who did not have a Plusoptix result (Mann–Whitney  $z=3.9$  right eyes, and  $2.4$  left eyes,  $p<0.001$  and  $p=0.02$ ).

Figure 2 and Table 4 highlight the Bland Altman analysis of ellipsoid spectacle image resolution grade comparing the ability of SBARS and of Plusoptix to target cycloplegic exam. For the 130 right eye hyperopic patients, ellipsoid for the Plusoptix  $2.38$  was greater than for SBARS  $0.90$  (Mann–Whitney  $z=8.2$ ,  $p<0.001$ ) and for the 132 left eyes Plusoptix  $2.49$  differed from SBARS  $0.72$  (Mann–Whitney  $z=9.0$ ,  $p<0.001$ ).

The Ellipsoid for all 170 completed Plusoptix of median  $2.33$  differed from the corresponding estimates by SBARS right eyes  $0.80$  (Mann–Whitney  $z=9.6$ ,  $p<0.001$ ). For left eyes, Plusoptix estimates  $2.30$  differed from SBARS  $0.80$  (Mann–Whitney  $z=9.5$ ,  $p<0.001$ ).



**Figure 2** Bland Altman analysis of ellipsoid. Ellipsoid is a univariate metric that indicates the degree to which a candidate refraction matches the target with a small values scoring better and 1.0 indicating just 1 logMAR line blur and a value of 2 being 3 logMAR lines blur. The target is cycloplegic refraction and the candidates are school bus accommodation-relaxing skiascopy (SBARS) and Plusoptix A12 infrared photoscreener. Bland Altman compares both candidates in blue circles for right eyes and orange triangles for left eyes. The mean difference indicates that Plusoptix has about 1.5 more ellipsoid than SBARS especially for higher values.

The interactions and comparisons of factors influencing ellipsoid and refractive components are summarized in Table 5. There was a significant 2-way ANOVA interaction based on developmental delay combined with level of cooperation on right SBARS ellipsoid ( $F(2164) = 3.5, p=0.03$ ) but not for left SBARS ellipsoid ( $F(2164) = 1.7, p=0.18$ ). There was no interaction combining developmental delays and level of cooperation for Plusoptix right ellipsoid ( $F(2164) = 1.5, p=0.22$ ) and for left eye ( $F(2164) = 0.93, p=0.39$ ). By Kruskal–Wallis, there was no difference in SBARS

**Table 4** Bland Altman Analysis

A	B	Side	Mean Diff	Lower	Upper	STDEV Diff	ICC
Ellipsoid-SB	Ellipsoid-Px	Right	-1.4	-5.7	2.9	2.2	0.11
Ellipsoid-SB	Ellipsoid-Px	Left	-1.7	-5.9	2.9	2.2	0.05
SphEq-Cyclo	SphEq-SB	Right	0.15	-1.27	1.57	0.73	0.91
SphEq-Cyclo	SphEq-SB	Left	0.16	-1.18	1.51	0.69	0.92
SphEq-Cyclo	SphEq-Px	Right	0.39	-3.00	3.77	1.73	0.64
SphEq-Cyclo	SphEq-Px	Left	0.1	-3.28	3.48	1.73	0.69
Cyl-cyclo	Cyl-SB	Right	0.04	-0.74	0.81	0.40	0.95
Cyl-cyclo	Cyl-SB	Left	0.01	-0.73	0.74	0.38	0.94
Cyl-cyclo	Cyl-PX	Right	-0.19	-2.43	2.05	1.14	0.56
Cyl-cyclo	Cyl-PX	Left	-0.14	-2.41	2.14	1.16	0.56

**Notes:** Results from Bland Altman analysis comparing components of candidates (school bus accommodation relaxing skiascopy; SB and Plusoptix A12; Px) compared to cycloplegic exam (Cyclo) for right and left eyes of 191 children. Mean diff is the mean difference between compared variables while the STDEV diff is the standard deviation of the difference. ICC in the intraclass correlation coefficient.

**Table 5** Compared Influences on SBARS and Plusoptix Targeting Cycloplegic Refraction

Variable	Side	Candidate	Factor	Outcome	Statistic	Value	p
Ellipsoid	All four	Both	Direct	Unequal	K-W	212	<0.001
	Right	SBARS	Race	Equal	K-W	7.4	0.19
	Right	SBARS	Age-group	Unequal	M-W	2.2	0.03
	Right	SBARS	New-return	Equal	M-W	0.96	0.34
	Right	SBARS	Gender	Equal	M-W	0.5	0.6
	Right	SBARS	Gender 170	Equal	M-W	0.28	0.78
	Right	SBARS	Delay	Equal	M-W	0.16	0.88
	Right	SBARS	Cooperation	Equal	K-W	0.24	0.89
	Right	SBARS	Hyperopia	Equal	M-W	1.15	0.25
	Right	SBARS	Cylinder	Unequal	K-W	24.7	0.001
	Right	SBARS	Px-able?	Equal	M-W	0.71	0.48
	Right	SBARS	Px excess?	Unequal	M-W	4.6	<0.001
	Right	SBARS	Right Px	Unequal	M-W	9.8	<0.001
	Right	SBARS	Left SBARS	Equal	M-W	0.91	0.36
	Right	Plusoptix	Race	Equal	K-W	7	0.22
	Right	Plusoptix	Age-group	Equal	M-W	0.64	0.53
	Right	Plusoptix	New-return	Equal	M-W	0.18	0.86
	Right	Plusoptix	Gender	Equal	M-W	0.32	0.75
	Right	Plusoptix	Delay	Equal	M-W	0.85	0.4
	Right	Plusoptix	Cooperation	Equal	K-W	0.5	0.78
	Right	Plusoptix	Hyperopia	Equal	M-W	0.16	0.87
	Right	Plusoptix	Cylinder	Unequal	K-W	22.6	<0.001
Right	Plusoptix	Left Plusoptix	Equal	M-W	0.55	0.59	
Left	Plusoptix	Px excess?	Unequal	M-W	6	<0.001	
Left	SBARS	Left Px	Unequal	M-W	10.7	<0.001	
Sph. Eq.	All six	All	Direct	Equal	K-W	9.1	0.1
	All six	Hyperopia	Direct	Unequal	K-W	20.7	0.001
	All four	Hyperopia	Delta	Equal	K-W	3.4	0.33
Over-Minus	Right	SBARS	Cooperation	Not independent	Chi-Square	7.8	0.02
	Right	Plusoptix	Cooperation	Independent	Chi-Square	5.9	0.05
J vector	All four	Both	Distributions	Unequal	Kolmogorov–Smirnov	11.7	<0.001
	All four	Both	Direct	Unequal	K-W	26	<0.001
K-W is Kruskal–Wallis			M-W is Mann–Whitney				

**Notes:** Due to non-normal distributions of data, non parametric tests Kruskal–Wallis (K-W) and Mann–Whitney (M-W) are used with Chi square for proportions. Candidate dry refractions from school bus accommodation-relaxing skiascopy (SBARS) and Plusoptix A12 (Px) or both targeting cycloplegic refraction in 191 high-risk pediatric patients of whom 21 had no reading on Plusoptix and another 21 had excess hyperopia/myopia interpreted on Plusoptix. Variables include ellipsoid univariate spectacle compare, spherical equivalent (Sph Eq), and the proportion with candidate more than 1 diopter over minus from cycloplegia.



ellipsoid by race for right eyes ( $X^2(7) = 8.1, p=0.32$ ) and left eyes ( $X^2(7) = 5.7, p=0.57$ ). By Kruskal–Wallis, the median SBARS ellipsoid did not differ by spherical equivalent refractive error designation (hyperopia > 0.75D myopia <1.0D and emmetropia in between) for ellipsoid right eyes ( $X^2(2) = 2.5, p=0.29$ ) and left eyes ( $X^2(2) = 4.3, p=0.12$ ).

The influence of new photoscreen referral versus long-term spectacle follow-up exams is shown in Table 6. The new photoscreen refer have never worn spectacles and many suffer from excess hyperopia, whereas the return patients have been accustomed to wearing spectacles that therapeutically compensate for excess hyperopia. There was no significant difference in ellipsoid or spherical equivalent based on prior wearing of spectacles in this high-risk cohort. The new patients with Plusoptix results directly referred by photoscreening (n=85 of the total 95) were compared to an equal number of follow-up patients (n=85) many of whom were already wearing spectacles. There was no difference in median values of ellipsoid right or left eye for SBARS or Plusoptix based on new referral or follow-up patients already in spectacles (Mann–Whitney z between 0.18 and 1.19, p value from 0.24 to 0.89). There was also no difference in median spherical equivalent right or left eye for cycloplegic exam, SBARS or Plusoptix relative to new referral or follow-up exam status (Mann–Whitney z between 0.03 and 1.1, p value from 0.27 to 0.98).

The influence on sub-components of the ellipsoid, J45 vector and M spherical equivalent is shown in Table 7 for SBARS and Plusoptix targeting cycloplegic exam. There was more influence of spherical equivalent than the astigmatic aspect of J45 vector separating SBARS performance compared to Plusoptix.

Regarding the influence of Plusoptix non-readability cases, the ellipsoid for SBARS corresponding to the 20 Plusoptix non-read right eye median of 1.05 did not differ from those with 170 with PlusoptiX read 0.80 (Mann–Whitney  $z=0.32, p=0.75$ ) and the left eye non-read median 1.07 versus reads 0.70 (Mann–Whitney  $z=0.56, p=0.58$ ).

## Amblyopia Risk Factor Screening

Figure 3 shows the receiver operating characteristic (ROC) curves screening by Plusoptix A12 and SBARS for age-based 2021 AAPOS amblyopia risk factors.<sup>11</sup> AAPOS 2021 amblyopia risk factor sensitivity/specificity for Plusoptix under age

**Table 6** Comparisons of NEW Photoscreen Referral versus RETURN Spectacle Visit Status

			Median			
		Eye	NEW	RETURN	M-W z=	p
Ellipsoid	SBARS	Right	0.9	0.71	0.91	0.37
	SBARS	Left	0.71	0.71	0.45	0.65
	PlusoptiX	Right	1.86	1.7	0.18	0.89
	Plusoptix	Left	1.99	1.68	1.19	0.24
SphEq	Cycloplegic	Right	1.13	0.88	0.52	0.6
	Cycloplegic	Left	1	1	0.54	0.59
	SBARS	Right	0.75	1	0.03	0.98
	SBARS	Left	0.75	0.75	0.27	0.79
	PlusoptiX	Right	0.75	0.5	0.89	0.38
	Plusoptix	Left	0.75	0.5	1.1	0.27

**Notes:** Ellipsoid is univariate comparison of candidate versus target cycloplegic exam. The candidates are school bus accommodation-relaxing skiascopy (SBARS) and Plusoptix photoscreener. Median values are compared with Mann–Whitney (M-W) statistic with p-values given. Spherical equivalent (SphEq) from the refractions is the sphere plus cylinder/2.

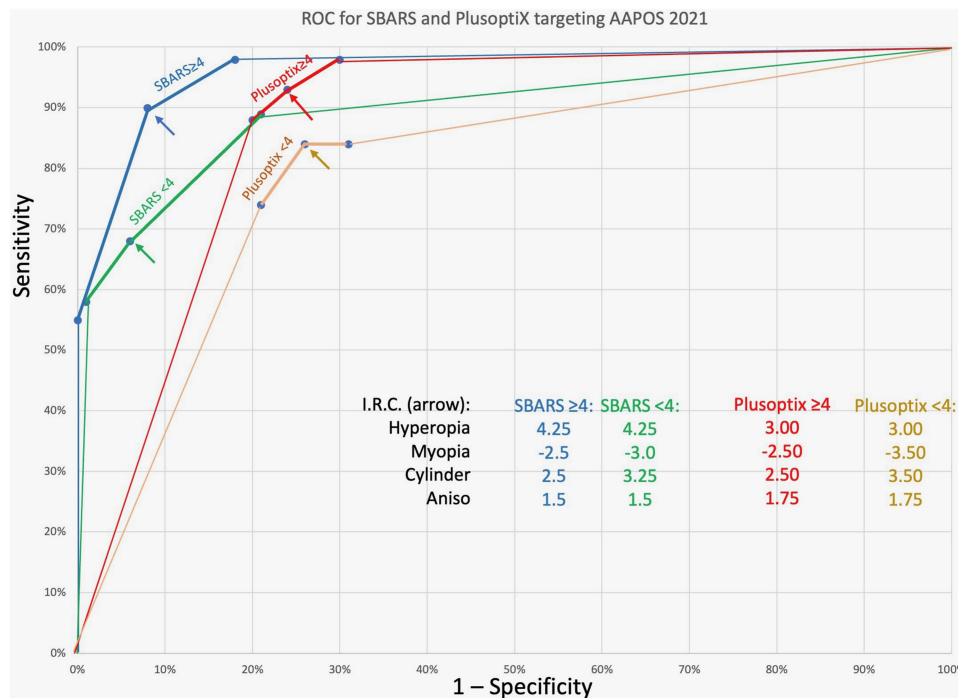
**Table 7** J45 and M Components of Ellipsoids Compared

	Eye	Medians			SBARS Vs Cyclo		Px vs Cyclo	
		Cyclo	SBARS	Plusoptix	M-W z=	p	M-W z=	p
J45	Right	-0.25	-0.25	-0.27	1.56	0.12	2.02	0.04
J45	Left	-0.25	-0.25	-0.23	1.32	0.19	2.66	0.01
M	Right	1	0.88	0.63	1.09	0.28	2.29	0.02
M	Left	1	0.75	0.62	1.11	0.27	1.71	0.09

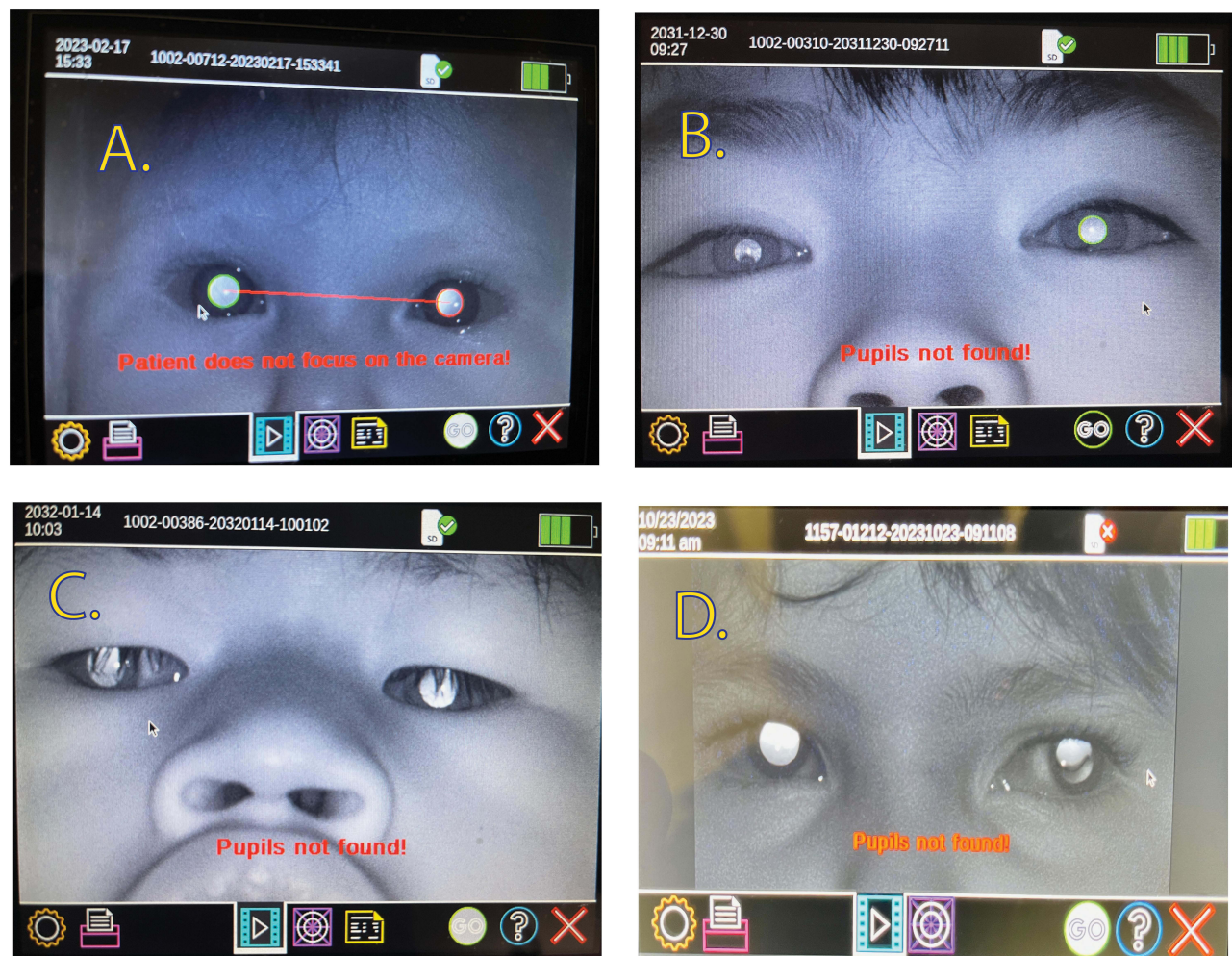
**Notes:** Refractions can be compared by converting sphero-cylinder into M (spherical equivalent) and J0 and J45 vector transformed components. For the Ellipsoid univariate spectacle comparison, J0 is adjusted to a value of zero. J45 is similarly adjusted and is calculated from  $-(\text{cylinder}/2)\sin(2 \text{ axis})$ . The target refraction is the cycloplegic exam (cyclo) while candidates are school bus accommodation-relaxing skiascopy (SBARS) and Plusoptix photoscreen (Px). Median values are given and compared with Mann-Whitney (M-W) statistics with p values given.

4 years was 84%/74% while for over age 4 years 93%/76%. The corresponding sensitivity/specificity values for SBARS for under 4 years were 68%/94% and for over 4 years 90%/92%.

There were additional benefits of pre-cycloplegic screening. The invisible infrared aspect of Plusoptix photo-screening can be very valuable for certain patients. The device gives a high-quality image of the red reflex showing features such as pupil anomalies like Horner’s syndrome with dark irides, media opacity and lens dislocation (Figure 4). For patients with intense photophobia, the infrared imaging may allow red reflex exam otherwise impossible without examination under anesthesia. The real-time gradual response to SBARS presenting an increasing plus lens over the non-streaked eye yields information on the facility to accommodate for that patient.



**Figure 3** Receiver Operating Characteristic (ROC) curve screening the APOS 2021 Amblyopia risk factors. The APOS 2021 failure criteria from cycloplegic exam are separated for 100 children under age 4 years and for 91 children 4 years and over. Non-contact, screening devices are the school bus accommodation-relaxing skiascopy (SBARS) and multi-radial infrared Plusoptix A12 photoscreener. Arrows indicate an optimum instrument referral criteria for instrument estimation of hyperopia, myopia, cylinder and meridional anisometropia listed below the curves.



**Figure 4** Red reflex images from infrared Plusoptix devices can show anterior segment and ocular media pathology even in intensely photosensitive patients. (A) Horner Syndrome (B) Corneal ulcer. (C) Trichiasis, (D) Ectopia lentis. (Parental permission given).

## Discussion

Non-contact, non-cycloplegic estimates of refractive error were judged in terms of the degree of hyperopia uncovered and by the ability to provide an optically similar spectacle. In a clinical situation with challenging, high-risk children for whom issues of time or cooperation limit the completion of the intended cycloplegic refraction, how reliable would pre-cycloplegic methods be? Both SBARS and Plusoptix performed well. SBARS was a bit more accurate, with more hyperopia uncovered and less over-minus prescription estimates. In this high-risk population, Plusoptix was quicker, but had more un-readable results (21 of 191) and an additional 21 (11 right eyes and 17 left eyes) interpreted as excess hyperopia or myopia.

The good vision screening ROC performance on these high-risk patients resembled the similar performance when selecting the instrument referral criteria for the three major infrared photoscreeners.<sup>21</sup> To date, very few studies have addressed the recent 2021 AAPOS amblyopia risk factor definitions,<sup>11,22,23</sup> especially for children less than 4 years of age. Plusoptix is a quick, efficient infrared interpreted photoscreener capable of providing an accurate spherocylinder refraction with accommodation well controlled in most patients. The infrared image from Plusoptix can also yield clinically helpful information about the red reflex even in otherwise photophobic patients. SBARS is also non-contact but requires nearer proximity to the patient's face. SBARS is capable of uncovering more than 90% of cycloplegic hyperopia and provides a high-grade estimate of cycloplegic refraction. By adjusting the working

distance with the ten convex lenses of SBARS, the single rack substitutes for a whole drawer of loose lenses in an easily carried tool.

Cycloplegia is intended to uncover hyperopia indeed remaining the gold-standard for uncovering hyperopia, but in some patients, it can disrupt cooperation for retinoscopy due to prolonged memory of the painful instillation process. Atropine can uncover more hyperopia than cyclopentolate,<sup>24</sup> especially when provided on a daily basis, but may require a return visit. Both Plusoptix and SBARS uncovered much hyperopia, with SBARS uncovering more (93% even in these high-risk patients). Plusoptix uses a large smiley face and sound to elicit fixation and focus, whereas different fixation targets can trigger more or less accommodation from photoscreening devices.<sup>12</sup> SBARS utilizes the principle of fogging<sup>25–27</sup> to uncover hyperopia and since the bus is held horizontally, uncovers more hyperopia than a vertically held lens rack<sup>18</sup> and exceeding the cycloplegic benefit of tropicamide versus cyclopentolate.<sup>28</sup>

Prior use and familiarity with spectacles might alter a child's customary level of accommodation, however we found the degree of spherical equivalent and the estimate of spectacle optical precision to be similar whether patients were new photoscreen referrals versus those patients with months to years of spectacle use.

Accurate, quick and child-friendly refraction remains complicated, especially in high-risk pediatric patients who are either too young to cooperate with table-top autorefractors, or who have developmental delays. The Nidek Handy Ref-K at 5 cm uncovered less hyperopia in children than the Welch Allyn SPOT aimed from 100 cm.<sup>29</sup> The Grand Seiko open autorefractor and the Topcon KR800 devices were fairly helpful in school-aged Chinese children.<sup>30</sup> A brief evaluation suggested that the new QuickSee handheld autorefractor was useful in children with or without cycloplegia.<sup>31</sup> Plusoptix performed nearly as well as the hand-held autorefractor Retinomax with<sup>32,33</sup> or without<sup>34–36</sup> cycloplegia and can be helpful, but young or developmentally challenged children might not participate with steady fixation given the close proximity required by the device. In a previous study, grade B or better spectacle match was achieved by 41% of Plusoptix and 65% for Retinomax.<sup>15</sup> SBARS also has a school bus with windows near to the child's face but is often less stressful and better tolerated by children. Some young children initially fixate on the printed diopter labels adjacent to the SBARS windows but can view through the convex lenses with encouragement. We found 93% of SBARS achieved grade B or better. We had approximately 10% poor cooperation some with Plusoptix, some with SBARS and some with both dry methods, but about 60% were upset with the instillation of cycloplegic drops. Plusoptix usually gives a rapid spherocylinder result in children with minimal refractive error. On the other hand, in this high-risk population approximately 10% could not yield a Plusoptix result, and another 10% were interpreted as having excess myopia (MYO) or excess hyperopia (HYP) without a specific spherocylinder designation. For this reason, photoscreening clinics should be encouraged to refer patients with a "no result" yield from the Plusoptix.

## Conclusion

Though designed to be utilized in pediatric and community-based lay screening, the Plusoptix autorefractor in the pediatric eye specialty clinic provides good estimation of gold-standard cycloplegic refraction with a 30% underestimation of full hyperopia by as much as 1.5 diopters. The SBARS technique provided excellent estimation of cycloplegic refractive error and uncovered more than 92% of cycloplegic hyperopia. Both techniques are quick, non-contact and generally well tolerated by children, and they both screen well for amblyopia risk factors but require some experience, especially with young, uncooperative, and developmentally delayed patients.

Precis: Non-contact photoscreening designed to be used in the pediatrician environment was tested in an eye clinic with high-risk pediatric eye patients along with horizontally held, convex skiascopy. Both dry methods provided helpful, quick estimates of spherocylinder refraction, with Plusoptix having more un-readable and a bit less accurate spectacles compared to cycloplegic confirmatory exams.

## Abbreviations

AAPOS, American Association for Pediatric Ophthalmology and Strabismus; ABCD, Alaska Blind child Discovery charitable research Project; ABCD ellipsoid, univariate metric for similarity of two spherocylinder refractions based on relative blur of the candidate compared to the target; ANOVA, analysis of variance; Cyl, cylinder measure of astigmatism; D, diopter; HIPAA, Health Insurance portability and Accessibility Act; HYP, Plusoptix interpretation of

high hyperopia greater than +5 diopters.; ICC, intraclass correlation coefficient; IQR, inter-quartile range; IQR1 is first and IQR3 is third; J0, spherocylinder spectacle vector transform Cartesian component; J45, spherocylinder spectacle vector transform oblique component; K-W, Kruskal–Wallis; logMAR, logarithm of the minimum angle of resolution; M; spherical equivalent; Mean Diff, Bland Altman mean difference between matched data pairs.; MYO; Plusoptix interpretation of high myopia beyond -7 diopters; M-W, Mann–Whitney; OD, oculo dexter – right eye; OS, oculo sinister – left eye; P, probability; Px, Plusoptix A12 model of photoscreener; Px read, Plusoptix screening that gives either spherocylinder or excess sphere interpretation; Px Rx, Plusoptix screening that yields a spherocylinder result; ROC, receiver operating characteristic; SB, school bus; SBARS, school bus accommodation-relaxing skiascopy; SphEq, spherical equivalent; STDEV Diff, standard deviation of the difference of each Bland Altman data pair; VIPS, vision in preschoolers study.

## Data Sharing Statement

<https://www.abcd-vision.org/references/SBARS%20PX%20De-ID%202023.pdf>.

## Disclosure

Dr Arnold coordinates the Alaska Blind Child Discovery, which has received discounted vision screening technology from several vendors. Dr Arnold is a board member of PDI Check, LLC; consultant for Neolight, outside the submitted work. In addition, Dr Arnold has a patent “Systems and Methods for Eye Evaluation and Treatment” issued. The authors report no other conflicts of interest in this work.

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