Comparison of refractometric measurements obtained with a portable autorefractor and conventional methods of refraction in schoolchildren

Comparação de medidas refratométricas obtidas com autorrefrator portátil e métodos convencionais de refração em escolares

Juliana Albano de Guimarães[1], **Nilza Minguini**[1], **Keila Miriam Monteiro de Carvalho**[1]

[1] Department of Ophthalmology and Otorhinolaryngology, Faculdade de Ciências Médicas, Universidade Estadual de Campinas, Campinas (SP), Brazil.

How to cite:
Guimarães JA, Minguini N, Carvalho KM. Comparison of refractometric measurements obtained with a portable autorefractor and conventional methods of refraction in schoolchildren. Rev Bras Oftalmol. 2024;83:e0020.

doi:
https://doi.org/10.37039/1982.8551.20240020

Keywords:
Ocular refraction; Refractive errors; Retinoscopy; Photoscreening; Autorefractor; Portable refractor

Descritores:
Refração ocular; Erros de refração; Retinoscopia; Photoscreening; Autorrefrator; Refrator portátil

Received on:
Jun 19,2023

Accepted on:
Aug 31, 2023

Corresponding author:
Juliana Albano de Guimarães
Departamento de Oftalmologia e Otorrinolaringologia, Faculdade de Ciências Médicas, Universidade Estadual de Campinas
Rua Vital Brasil, 251 – Cidade Universitária
Zip code: 13083-888 – Campinas, SP, Brazil
E-mail: julianaalbanog@gmail.com

Institution:
Department of Ophthalmology and Otorhinolaryngology, Faculdade de Ciências Médicas, Universidade Estadual de Campinas, Campinas (SP), Brazil.

Conflict of interest:
no conflict of interest.

Financial support:
Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), protocol 2016/06960-4.

ABSTRACT

Objective: To assess the performance of a portable autorefractor as refractor and screening tool for refractive errors in schoolchildren.

Methods: Cross-sectional observational study. Refractometric measurements of children between 5 and 10 years old were obtained through four methods: 2WIN under non-cycloplegic conditions, and 2WIN, conventional autorefractor, and retinoscopy, under cycloplegic conditions. Correlations and agreement between the methods and accuracy of the portable autorefractor to define whether to prescribe glasses were assessed.

Results: The mean age ± standard deviation was 6.87 ± 1.42 years. The portable autorefractor without cycloplegia showed a high correlation with retinoscopy (0.77) but tended to underestimate hyperopia and overestimate high astigmatism. Regarding screening for prescription of glasses in comparison with the reference method "retinoscopy," the sensitivity of the portable autorefractor without cycloplegia was calculated to be 100,00% and the specificity, 34.3%.

Conclusion: The portable autorefractor should be used as a screening tool and, when prescribing glasses, the tendency of underestimating hyperopia and overestimating high astigmatism should be kept in mind.

RESUMO

Objetivo: Avaliar o desempenho de um autorrefrator portátil como refrator e ferramenta de triagem para erros de refração em crianças em idade escolar.

Métodos: Estudo observacional transversal. As medidas refratométricas de crianças de 5 a 10 anos foram obtidas por meio de quatro métodos: 2WIN em condições não cicloplégicas e 2WIN, autorrefrator convencional e retinoscopia, em condições cicloplégicas. Foram avaliadas as correlações e a concordância entre os métodos e a acurácia do autorrefrator portátil para definir a prescrição de óculos.

Resultados: A média de idade ± desvio-padrão foi de 6,87 ± 1,42 anos. O autorrefrator portátil sem cicloplegia apresentou alta correlação com a retinoscopia (0,77), mas tendeu a subestimar a hipermetropia e a superestimar o alto astigmatismo. Em relação à triagem para prescrição de óculos em comparação com o método de referência retinoscópio, a sensibilidade do autorrefrator portátil sem cicloplegia foi calculada em 100,00% e a especificidade, em 34,3%.

Conclusão: O autorrefrator portátil deve ser usado como ferramenta de triagem e, ao se prescreverem óculos, deve-se ter em mente a tendência de subestimar a hipermetropia e superestimar o alto astigmatismo.

INTRODUCTION

Visual screening aims to prevent blindness and promote eye health.[1] The main purpose of visual screening in schoolchildren is the detection of refractive errors which, when not corrected, are the leading cause of visual impairment and the second leading cause of blindness worldwide.[2] Estimates show that 20% of schoolchildren have some eye condition, including refractive errors, amblyopia, strabismus, conjunctivitis, and trauma sequelae.[1] Low visual acuity during the school phase has an impact on learning and socialization, contributing to learning deficits, worse performance at school, comorbidities such as headaches and cervical, thoracic and lumbar pain, bullying and difficulties in social development, which leads to lifelong negative impacts.[2-4]

Portable autorefractors (such as PlusOptix, 2WIN photoscreener, Otago screener, Sure Sight, Retinamx®, MTI photoscreeners, iScreen Vision Screener, among others) are devices that use different computational processing mechanisms useful for the detection and quantification of ametropias, media opacities, and misalignment of the eyes.[5-7] Obtaining refraction using portable autorefractors is fast, since the child only needs to fixate for a short period of time, and the use of cycloplegic eye drops for temporary paralysis of accommodation is dispensed.[8]

Several studies have proven the effectiveness of most portable autorefractors as a method of tracking refractometric errors, under cycloplegic conditions or not, when compared to gold standard retinoscopy under cycloplegia.[6-25]

The purposes of this study were: to compare results of refractometric measurements obtained through the portable autorefractor, autorefractor and retinoscopy, under cycloplegic and non-cycloplegic conditions; and to assess the accuracy of the portable autorefractor as a screening tool for refractive errors in the school age group in our population.

METHODS

Subject population

The present study was carried out with the approval of the Research Ethics Committee of the Universidade de Campinas (Unicamp), CAAE: 13922619.4.0000.5404, and was conducted in accordance with the tenets of the Declaration of Helsinki and current legislation on clinical research. Written informed consent was obtained from the children's guardians and informed consent was obtained from the children, after explanation of the procedures.

Participants were selected by convenience, at the Ophthalmology Outpatient Clinic of the Hospital de Clínicas of the Faculdade de Ciências Médicas of Unicamp. Children between 5 and 10 years old who agreed to participate and whose parents accepted to participate in the study were included. Children whose techniques could not be applied due to the presence of media opacities, such as corneal, lens, and vitreous opacities, were excluded.

Examinations

Visual acuity was measured by the Snellen chart, monocularly, at 6m.

The refractometric measurements were obtained using:

- 2WIN portable autorefractor (Alaska Blind Child Recovery; Adaptica, Padova, Italy), before and after cycloplegia, in a darkened room, one meter from the child. 2WIN is a portable infrared photoscreener, licensed in Brazil by the Agência Nacional de Vigilância Sanitária (Anvisa). It estimates, in about 7 seconds, the refractive error and binocular alignment through infrared photoscreening, using targets at distance to prevent accommodation.[16] Measurements were repeated until the device would point out that the assessment was reliable (highest quality score).
- PAK-8000 autorefractor (POTEC), after cycloplegia.
- Retinoscopy (18245 retinoscope from Welch Allyn), performed by a single examiner, after cycloplegia.

Cycloplegia was obtained with two instillations of 1% cyclopentolate with a five-minute interval between them. Examinations under cycloplegia were performed 45 minutes after the last application.

Refraction measurements were expressed in spherical diopters for the spherical component, cylindrical diopters for the cylindrical component, and degrees for the main axis of the cylinder.

Glasses were prescribed after subjective examination in cases of cooperative children and based on the retinoscopy in cases of uncooperative children. The prescription followed the criteria recommended by the Brazilian Council of Ophthalmology in 2016:[26] a) ≥ +3,00 diopters (D) of hyperopia; b) ≥ -0,.75 D myopia; c) ≥ -0,75 D of astigmatism; and d) the above parameters were used as a reference only in children without specific symptoms. In case of prescription, the values prescribed were the static refractometry values that presented the best visual acuity in the lens test, with 1.0 spherical diopter being discounted in case of hyperopia.

Statistical analysis

Data were analyzed using the program R version 4.2.1.

To perform statistical analyses, readings were converted into power vectors, as described by Thibos et al.[27] Spherical equivalent (SE) was calculated as SE = S + C/2, S being the spherical component and C, the cylindrical component. The vector presentation of astigmatism comprises J0 representing Cartesian astigmatism (vertical Jackson cross cylinder with positive indicating with-the-rule and negative against-the-rule astigmatism) and J45 representing oblique Jackson cross cylinder astigmatism. J0 and J45 were calculated according to the following formulas: $J0 = (-C/2)*\cos(2*\theta)$; and $J45 = (-C/2)*\sin(2*\theta)$, respectively.

Data were tested for normality using the Shapiro-Wilk test. The distribution of the data was assumed as normal when the p-value was above 0.05. Once the continuous variables in this study were not normally distributed, they were presented as median and range (minimum value, quartiles, and maximum value).

The Friedman test was performed to assess whether the methods were statistically different. The post-hoc Wilcoxon signed-rank test was then used to compare each two paired methods, with the Bonferroni adjusted p-value method. For all tests, a p-value was considered significant when less than or equal to 0.05.

Correlations were assessed through the intraclass correlation coefficient. Correlations were considered weak if r was below 0.3, moderate if r was between 0.3 and 0.7, and strong if r was higher than 0.7.

Agreement between the refractometric results of 2WIN without cycloplegia and cycloplegic retinoscopy was investigated via Bland–Altman analysis.

Accuracy of 2WIN to define whether to prescribe glasses was assessed using 2x2 tables, following the recommendations by the Brazilian Council of Ophthalmology in 2016, previously described. The variables were mutually exclusive: yes (glasses should be prescribed) versus no (glasses do not need to be prescribed). The refractometric measurements obtained with 2WIN, before and after cycloplegia, were analyzed based on the gold standard retinoscopy. Specificity and sensibility were calculated based on the 2 x 2 tables.

RESULTS

A total of 30 participants, 60 eyes, were included in the study. Half of them were female and their age ranged between 5 and 10 years (mean 6.87±1.42). Both eyes of each patient were included.

Four refraction measurements were obtained: non-cycloplegic refraction by 2WIN; cycloplegic refraction by 2WIN; cycloplegic refraction by the conventional autorefractor; cycloplegic refraction by retinoscopy. Cycloplegic refraction by 2WIN was not obtained in 3 participants, for reasons intrinsic to the portable autorefractor.

Sample normality

The Shapiro-Wilk test disclosed the data as not normal based on the values obtained by the non-cycloplegic 2WIN (p=0.015), the cycloplegic 2WIN (p=0.014), and the cycloplegic autorefractor (p=0.016). The retinoscopy values were found to be normal (p=0.236).

Correlation between the methods

The intraclass correlation coefficient (ICC) is shown in table 1. The ICC disclosed a good correlation between the methods for the SE, but not for the astigmatic vectors.

Table 1. Intraclass correlation coefficient for the spherical equivalent, J0 and J45

	Spherical equivalent	J0	J45
ICC	0.77	-0.07	0.10
95% confidence interval	0.68-0.85	-0.14-0.03	0.003-0.22

ICC: intraclass correlation coefficient; MV: macular volume.

Agreement between non-cycloplegic 2WIN and cycloplegic retinoscopy

In relation to agreement between refractometric values obtained with non-cycloplegic 2WIN and cycloplegic retinoscopy, the mean differences for non-cycloplegic 2WIN minus cycloplegic retinoscopy were found to be -0.53 (-0.73 to -0.33) for the SE, -0.31 (-0.55 to -0.07) for J0, and 0.56 (0.32 to 0.80) for J45. The minus value indicates an underestimation of hyperopia and overestimation of myopia by 2WIN when compared to cycloplegic retinoscopy.

The estimate and confidence interval of the bias, the lower and the upper limit of agreement for the differences between non-cycloplegic 2WIN, and cycloplegic retinoscopy are represented in figure 1. The range of the intervals of agreement was 3.05 D for the SE, 3.66 for J0, and 3.64 for J45. Linear regression applied to the plot disclosed that these differences depended on the mean values, with greater bias being found for more hyperopic means (in the SE graph) and for more astigmatic means (in the J0 and J45 graphs).

Accuracy for glasses prescription

Regarding the prescription of glasses, the number of students who would receive the prescription after

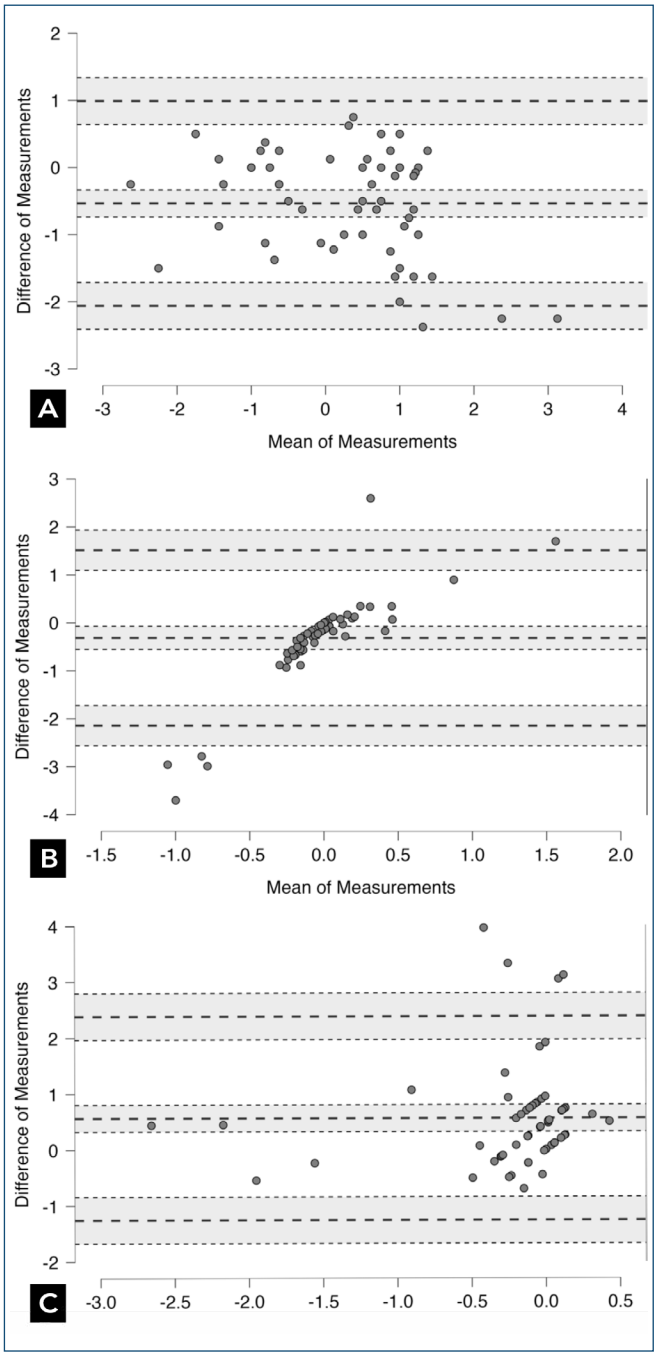

Figure 1. Bland-Altman plot with best fit line comparing the spherical equivalent (A), J0 (B) and J45 (C) measured through non-cycloplegic 2WIN and cycloplegic retinoscopy.

examination with 2WIN without and with cycloplegia, based on measurements obtained with retinoscopy, is shown in table 2. Three participants (six eyes) were excluded from the analysis regarding 2WIN with cycloplegia due to the impossibility of measurement by 2WIN.

In comparison with the reference method "retinoscopy", the sensitivity of 2WIN without cycloplegia was calculated to be 100,00%. Specificity was calculated at 34.3%. The positive predictive value (PPV) was 52,1% and the negative predictive value (NPV), 100%. The accuracy of 2WIN without cycloplegia in relation to retinoscopy was 61.7%.

Table 2. Indication for prescription of glasses by 2WIN without and with cycloplegia, based on measurements obtained with retinoscopy

	Retinoscopy			
2WIN without cycloplegia	Glasses	Yes	No	Total
	Yes	25	23	48
	No	0	12	12
	Total	25	35	60
	Retinoscopy			
2WIN with cycloplegia	Glasses	Yes	No	Total
	Yes	21	17	38
	No	0	16	16
	Total	21	33	54

Compared to the reference method "retinoscopy", the sensitivity of 2WIN with cycloplegia was calculated to be 100% and the specificity, 48.5%. The PPV was 55.3% and the negative predictive value was 100%. The accuracy of 2WIN with cycloplegia in relation to retinoscopy was 68.5%.

DISCUSSION

Portable autorefractors are small, easy-to-use, fast devices that require little cooperation on the part of the subjects being examined. Regarding school children, refractometric measurements obtained by these devices could be a valuable tool in routine ophthalmological consultation, especially in uncooperative children, with behavior alteration disorders or delayed neuropsychomotor development.[6-25]

Portable autorefractor as a screening tool

Ideally, a screening tool must identify a high proportion of individuals with the problem in question (high sensitivity) and a high proportion of individuals without the problem in question (high specificity). According to our data and the Brazilian Council of Ophthalmology recommendations for glasses prescription, the portable autorefractor showed high sensitivity (100%) when compared to retinoscopy, the gold-standard method. However, the specificity of the portable autorefractor with and without the cycloplegia was low (34.3% and 48.5%, respectively). In practical terms, this indicates that a relatively large percentage of children evaluated by the portable autorefractor would be considered candidates for the prescription of glasses without really needing it. On the other side, in face of a portable autorefractor result indicating no need for glasses prescription, 100% will not indeed be prescribed (negative predictive value).

Our findings agree with those of previous studies that assessed the use of portable autorefractors for visual tracking. Ransbarger et al. used the SPOT Vision Screening® in a Hispanic population of 300 preschool children and showed a specificity of 55.70%.[24] Schmucker et al. carried out a review on the effectiveness of visual screening in 300 preschool children and found sensitivity values between 46% and 95% and specificity values between 53% and 100%.[25] Gonçalves et al. studied the performance of 2WIN as a visual screening tool in children between 6 months and 3 years, showing 100% sensitivity, 93.18% specificity, and 93.26% of accuracy under dynamic accommodation conditions in relation to retinoscopy. As in the present study, cycloplegia did not bring significant gains in sensitivity and specificity.[15]

Portable autorefractor as an autorefractor

In terms of refraction reliability, our results demonstrated that the correlation of the methods was high, considering the SE (ICC=0.773). A mean difference of -0.53 diopters between the SE results of non-cycloplegic portable autorefractor and cycloplegic retinoscopy probably accounts for this correlation to be smaller than it could potentially be, once the hyperopia tends to be underestimated. However, clinically, some authors consider a difference of less than ± 1.00 D SE between methods irrelevant,[16] turning a difference of -0.53 reasonably accepted and the agreement between the methods quite fair.

Proportionally greater differences were found for greater hyperopic and astigmatic means, when analyzing non-cycloplegic portable autorefractor and cycloplegic retinoscopy. The regression line applied to the Bland-Altman plot showed that, for higher mean values of spherical component (hyperopic refractions), the difference between the measurements tended to be more negative, indicating an underestimation of hyperopia. We believe this could possibly be due to the lack of cycloplegia and due to the proximity of 1m between the patient and the portable autorefractor at the time of the measurement, inducing some degree of accommodation. For lower mean values (myopic refractions), the differences between the measurements tended to be closer to zero. On its turn, the regression line in the cylindrical component graph showed that, for greater cylindrical measurements, the difference between the methods increased, indicating a worse agreement. For these reasons, we must stress that the portable autorefractor may not be as precise as the conventional refractor for final prescription purposes.

Previous studies found similar results, such as Gonçalves et al., who identified adequate performance of 2WIN as a screening tool, but limitations regarding the accuracy of refractometry;[15] Cordonnier et al., who showed that Retinomax has good screening potential, but is limited as a refractor;[28] and Reddy, who demonstrated that Spot Vision is useful for visual screening in schoolchildren, although the refractometric values obtained by this device should be a guide for subjective refraction and not the final prescription.[29]

Joseph et al. observed strong agreement between prescriptions based on subjective refraction and on the QuickSee portable autorefractor in adults aged 18 to 40 years, concluding that prescription based on the portable autorefractor could be considered in low-resource settings.[30] In the school age group, Liu et al. compared school-aged refraction measurements using 2WIN-S (2WIN along with its recently developed "special light occlude tube") and cycloplegic retinoscopy and observed good reliability and high agreement between the methods.[14] However, as Liu et al. have pointed out, in children, even though the agreement between the refractions obtained with 2WIN-S without cycloplegia and by retinoscopy with cycloplegia was strong, it is not recommended to prescribe the refraction based on the measurements obtained by the portable autorefractor, since children accommodate, and dynamic refraction cannot be considered completely reliable.[14]

Study limitations

The limitations of the study include the small sample size and the fact that the study participants were children from public schools in Campinas, São Paulo, Brazil. Thus, the results obtained in this study have internal validity and should not be generalized to other populations.

CONCLUSION

We believe portable autorefractors could be useful in ophthalmological consultations of schoolchildren, mainly the uncooperative ones. Even so, although the portable autorefractor without cycloplegia showed a high correlation with retinoscopy, it tended to underestimate hyperopia and overestimate high astigmatism. Therefore, it is helpful as a screening tool but, when prescribing glasses, these findings should be kept in mind.

ACKNOWLEDGEMENT

To the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for funding this research. Process number 2016/06960-4.

AUTHORS' CONTRIBUTION

Albano de Guimarães J: conception and design, data acquisition, analysis and interpretation of data, manuscript writing, and critical revision of content, final approval of the submitted manuscript; Minguini N: conception and design, data acquisition, analysis and interpretation of data, participation in manuscript writing, and critical revision of content, final approval of the submitted manuscript; Carvalho KMM: conception and design, analysis and interpretation of data, participation in manuscript writing, and critical revision of content, final approval of the submitted manuscript.

All authors reviewed and approved the final version submitted for publication.

REFERENCES

1. Alves MR, Temporini ER, Kara-José N. Atendimento oftalmológico de escolares do sistema público de ensino no município de São Paulo - aspectos médico-sociais. Arq Bras Oftalmol. 2000;63(5):359-63.
2. Resnikoff S, Pascolini D, Mariotti SP, Pokharel GP. Global magnitude of visual impairment caused by uncorrected refractive errors in 2004. Bull World Health Organ. 2008;86(1):63-70.
3. Noma R, Carvalho RS, Kara-José N. Why are there defaulters in eye health projects? Clinics. 2011;66(9):1585-9.
4. Toledo CC, Paiva AP, Camilo GB, Maior MR, Leite IC, Guerra MR. Early detection of visual impairment and its relation with school effectiveness: Study in a sample of elementary education students of a midsize city in the Zona da Mata Mineira. Rev Assoc Med Bras. 2010;56(4):415-9.
5. Grossman DC, Curry SJ, Owens DK, Barry MJ, Davidson KW, Doubeni CA, et al. Vision screening in children aged 6 months to 5 years: US preventive services task force recommendation statement. JAMA. 2017;318(9):836-44.
6. Sanchez I, Ortiz-Toquero S, Martin R, de Juan V. Advantages, limitations, and diagnostic accuracy of photoscreeners in early detection of amblyopia: a review. Clin Ophthalmol. 2016;10:1365-73.
7. Yalcın E, Sultan P, Yılmaz S, Pallikaris IG. a comparison of refraction defects in childhood measured using Plusoptix S09, 2WIN photorefractometer, benchtop autorefractometer, and cycloplegic retinoscopy. Semin Ophthalmol. 2017;32(4):422-7.
8. Dahlmann-Noor AH, Vroutsou K, Kostakis V, Abou-Rayyah Y, Adams G, Brookes J, et al. Vision screening in children by Plusoptix Vision Screener compared with gold-standard orthoptic assessment. Br J Ophthalmol. 2009;93(3):342-5.
9. Racano E, Alessi S, Pertile R. Comparison of 2Win and plusoptiX A12R refractometers with Retinomax handheld autorefractor keratometer. J AAPOS. 2019;23(5):276.e1-276.e5.
10. Arnold SL, Arnold AW, Sprano JH, Arnold RW. Performance of the 2WIN photoscreener with "CR" strabismus estimation in high-risk patients. Am J Ophthalmol. 2019;207:195-203.
11. Martin SJ, Htoo HE, Hser N, Arnold RW. Performance of two photoscreeners enhanced by protective cases. Clin Ophthalmol. 2020;14:1427-35.
12. Donahue SP, Arthur B, Neely DE, Arnold RW, Silbert D, Ruben JB, et al. Guidelines for automated preschool vision screening: A 10-year, evidence-based update. J AAPOS. 2013;17(1):4-8.
13. Ogbuehi KC, Almaliki WH, Alqarni A, Osuagwu UL. Reliability and reproducibility of a handheld videorefractor. Optom Vis Sci. 2015;92(5):632-41.
14. Liu Z, Pazo EE, Ye H, Yu C, Xu L, He W. Comparing school-aged refraction measurements using the 2win-s portable refractor in relation to cycloplegic retinoscopy: a cross-sectional study. J Ophthalmol. 2021;2021:6612476.
15. Gonçalves BV, Carvalho KM, Minguini N, Alves MR, Souto FM. Comparison of refractometric measurements using 2WIN Photoscreener and manual retinoscopy in asymptomatic preschoolers. Rev Bras Oftalmol. 2021;80(1):27-32.
16. Jesus DL, Villela FF, Orlandin LF, Eiji FN, Dantas DO, Alves MR. Comparison between refraction measured by spot vision screening™ and subjective clinical refractometry. Clinics. 2016;71(2):69-72.
17. Kirk S, Armitage MD, Dunn S, Arnold RW. Calibration and validation of the 2WIN photoscreener compared to the PlusoptiX S12 and the SPOT. J Pediatr Ophthalmol Strabismus. 2014;51(5):289-92.
18. Longmuir SQ, Boese EA, Pfeifer W, Zimmerman B, Short L, Scott WE. Practical community photoscreening in very young children. Pediatrics. 2013;131(3):e764-e769.
19. Ugurbas SC, Kucuk N, Isik I, Alpay A, Buyukuysal C, Ugurbas SH. Objective vision screening using PlusoptiX for children aged 3-11 years in rural Turkey. BMC Ophthalmol. 2019;19(1):73.
20. Nielsen LS, Skov L, Jensen H. Visual dysfunctions and ocular disorders in children with developmental delay. I. prevalence, diagnoses and aetiology of visual impairment. Acta Ophthalmol Scand. 2007;85(2):149-56.
21. McCurry TC, Lawrence LM, Wilson ME, Mayo L. The plusoptiX S08 photoscreener as a vision screening tool for children with autism. J AAPOS. 2013;17(4):374-7.
22. Yanovitch T, Wallace DK, Freedman SF, Enyedi LB, Kishnani P, Worley G, et al. The accuracy of photoscreening at detecting treatable ocular conditions in children with Down syndrome. J AAPOS. 2017;14(6):472-7.
23. Curtis R, Hazari H, Eden K, Hopman WM, Irrcher I, Bona MD. Validation of a portable, remotely delivered refraction approach compared to standard in-clinic refraction in a low-vision population. J Telemed Telecare. 2022;28(9):662-9.
24. Ransbarger KM, Dunbar JA, Choi SE, Khazaeni LM. Results of a community vision-screening program using the Spot photoscreener. J AAPOS. 2013;17(5):516-20.
25. Schmucker C, Grosselfinger R, Riemsma R, Antes G, Lange S, Lagreze W, et al. Effectiveness of screening preschool children for amblyopia: A systematic review. BMC Ophthalmol. 2009;9(1):3.
26. Tartarella MB, Ferreira RC, Verçosa IMC, Fortes Filho JB. Recomendações sobre refração em crianças pré-verbais. eOftalmo. 2016;2(3):1-5. 10.17545/e-oftalmo.cbo/2016.60
27. Thibos LN, Wheeler W, Horner D. Power vectors: an application of Fourier analysis to the description and statistical analysis of refractive error. Optom Vis Sci. 1997;74(6):367-75.
28. Cordonnier M, Dramaix M. Screening for abnormal levels of hyperopia in children: A non-cycloplegic method with a handheld refractor. Br J Ophthalmol. 1998;82(11):1260-4.
29. Reddy S, Panda L, Kumar A, Nayak S, Das T. Tribal Odisha Eye Disease Study # 4: Accuracy and utility of photorefraction for refractive error correction in tribal Odisha (India) school screening. Indian J Ophthalmol. 2018;66(7):929-33.
30. Joseph S, Varadaraj V, Dave SR, Lage E, Lim D, Aziz K, et al. Investigation of the accuracy of a low-cost, portable autorefractor to provide well-tolerated eyeglass prescriptions: a randomized crossover trial. Ophthalmology. 2021;128(12):1672-80.