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Refractive error and ocular alignment in school-aged children from low-income areas of São Paulo, Brazil

Arthur Gustavo Fernandes[1,2*], Rodrigo Galvão Vianna[3,4], Debora Cristina Gabriel[4], Bruna Gil Ferreira[5], Eduardo Parente Barbosa[3,4], Solange Rios Salomão[1] and Mauro Campos[1,3,4]

Abstract

Background Uncorrected refractive errors and amblyopia are reported as the two main causes of childhood visual impairment and blindness worldwide. Our purpose was to evaluate refractive status, ocular alignment and effective refractive error coverage (eREC) of school-aged children from low-income areas of Sao Paulo city, Brazil.

Methods Data from the "Ver na Escola" Project were used for the current study. Children enrolled in the selected schools had an ophthalmic exam including eye alignment assessed by cover test, automatized and subjective dynamic and static refraction. The associations of demographic variables with occurrence and magnitude of refractive errors and eREC were investigated by multiple logistic regressions and multilevel mixed effect models.

Results A total of 17,973 children (51.12% females) with mean ± sd age 8.24 ± 3.54 years old examined from July 2018 to July 2019, were included in the study. Most of the participants (73%) showed orthoposition of the visual axis for both distance and near. Heterophoria was found in about 25% of participants (N = 4,498), with 71.7% of them (N= 3,222) classified as exophoria. Less than 2% (N = 232) showed strabismus, most of them (N = 160) esotropia. Overall, 1,370 (7.70%) of participants had myopia and 577 (3.24%) had hyperopia. Age was found to be significantly associated with increasing static subjective refraction spherical equivalent (Coefficient: -0.18; 95% Confidence Interval (CI): -0.21 to -0.16; $p < 0.001$). Female sex (Odds Ratio (OR) = 1.13; 95%CI: 1.01–1.27; $p = 0.027$) and older age (OR = 1.17; 95%CI: 1.16–1.19; $p < 0,001$) were significantly associated with myopia diagnosis. Older age decreased the odds of hyperopia (OR = 0.95; 95%CI: 0.93–0.98; $p < 0.001$). The overall effective refractive coverage was 51.76% and was significantly associated with age group, ranging from 32.25% in children aged 3 to 7 years to 61.35% in children aged 8 to 12 years.

Conclusions Most children have shown eye alignment for both distance and near assessments and no refractive error. Myopia was observed in 7.70% of the population and it was associated with older age and female sex. Hyperopia was observed in 3.24% and was associated with younger age. The overall eREC was 51.76%, significantly associated with age.

Keywords Epidemiology, Ophthalmology, Public health, Refractive errors, Visual impairment

*Correspondence:
Arthur Gustavo Fernandes
arthur_abz@yahoo.com.br
[1]Departamento de Oftalmologia e Ciências Visuais – Escola Paulista de Medicina, Universidade Federal de São Paulo (Unifesp), Rua Botucatu, 816, Sao Paulo, SP 04023-062, Brazil
[2]Department of Anthropology and Archaeology, University of Calgary, Calgary, AB, Canada
[3]Hospital de Olhos Paulista – H Olhos, São Paulo, SP, Brazil
[4]Instituto Verter, São Paulo, SP, Brazil
[5]Renovatio, São Paulo, SP, Brazil

Background

Accurately estimating the prevalence of visual impairment and blindness in children is challenging due to methodological difficulties and large sample sizes required for studying conditions with low frequency in the population [1, 2]. Recent studies indicate that the prevalence of blindness ranges from 0.2 to 7.8 per 10,000 children in low and middle-income countries, and about 6 per 10,000 children in developed countries for the under-15 age group [3]. The primary causes of childhood visual impairment and blindness are uncorrected refractive errors and amblyopia [4]. Additionally, there are notable differences in other underlying conditions: congenital cataract and infectious diseases are more common in low-income countries, while retinopathy of prematurity is more frequent in high-income countries [4].

Refractive errors can be classified into myopia, hyperopia, and astigmatism. Myopia is a condition usually associated with the elongation of the axial length and it is often referred as far vision impairment as distant objects appear indistinct while close objects appear clear [5]. Currently, 30–50% of adults in Europe and United States are myopic, and the condition can affect as many as 90% of high school students in East Asia [6–8]. Myopia has shown a significant increase in prevalence over the last two decades and the number of people affected by myopia worldwide is expected to increase from 1.4 billion to 5 billion by 2050, affecting approximately 50% of the world's population [9].

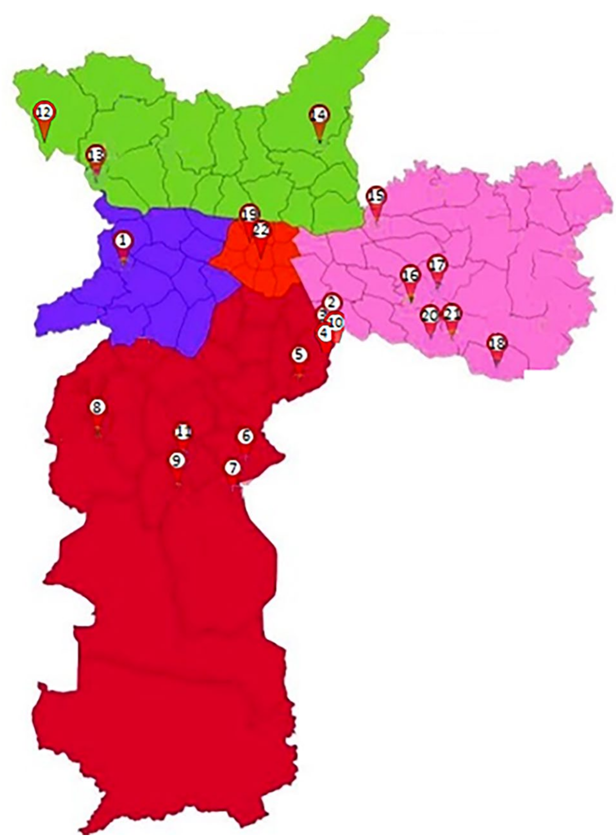

Fig. 1 Map of Sao Paulo with regions north (green), south (red), east (pink), west (purple), and center-east (orange), indicating the locations of the 22 educational centers selected to the *Ver na Escola* Project throughout the entire city

An increasing body of evidence highlights the potential of visual health initiatives to advance the Sustainable Development Goals (SDGs), contributing to objectives such as poverty reduction, zero hunger, good health and well-being, quality education, gender equality, and decent work. Notably, uncorrected refractive error stands out as a primary global cause of vision loss. Therefore, the World Health Organization (WHO) has incorporated the effective refractive coverage (eREC) indicator as a key parameter for assessing progress toward achieving the 2030 SDGs [10]. eREC is defined as the percentage of individuals in need of refractive error services, including spectacles, contact lenses, or refractive surgery, who have received these services and achieved positive outcomes.

Recently, an initiative from the São Paulo city government in partnership with a local non-governmental organization, the so-called project named "Projeto Ver na Escola" was launched aiming to offer visual screening and free-of-charge glasses to children enrolled in public schools of the city. A previous report has presented the frequency and causes of visual impairment and blindness in the study population [11].

The purpose of the current study is to determine refractive and eye alignment status and effective refractive error coverage of school-aged children from low-income areas of Sao Paulo city, Brazil.

Methods

"Ver na Escola" project

Our data was derived from the "Ver na Escola" Project, a Sao Paulo city government program in partnership with Institute Verter that offers visual screening to children enrolled in public schools of the city. Besides the visual screening, those with identified visual impairment are examined by an ophthalmologist in the school, and actions, including spectacles provision, are offered free-of-charge. The project was carried out in public educational institutions mainly Unified Educational Centers (CEUs), and reached all regions of the Municipality of São Paulo, Brazil. The city had 46 CEUs with 79,192 children aged 3 to 17 years old enrolled in the year 2018. According to the Paulista index of social vulnerability (IPVS), an index that measures the socioeconomic profile of each censorial sector in the Sao Paulo state, the Ver na Escola Project selected 22 CEUs distributed in different locations, including the south, east, center-east, west and north regional boards, as shown in Fig. 1. The current study include data collected in the Project from July 2018 to July 2019.

Ethical approval and informed consent

This study was approved by the Research Ethics Committee of the Hospital de Olhos Paulista (H.OLHOS) and was conducted in accordance with the tenets of the Declaration of Helsinki.

Prior to the testing, the children's guardians were asked to sign a consent form to participate in the current study. Only children whose guardians authorized participation were included.

Screening tests

Screening tests included presenting distance visual acuity (PVA) measured with currently used spectacles if participant was wearing them, ocular alignment assessed by cover/uncover test followed by alternate cover test at 33 cm and 4 m, and dynamic (i.e. non-cycloplegic) automatized refraction (KR 7000 S Topcon autorefractor).

Visual acuity was measured by experienced ophthalmic technologists using printed tumbling E logMAR charts at a four-meter distance. Visual acuity was measured from each eye separately and was recorded as the smallest line read with one or no errors. Testing for counting fingers, hand movement, and light perception were performed on those unable to read the top line at a one-meter distance. All the tests were performed in rooms with similar dimensions and standardized light sources ensuring consistency on the lightening conditions during the tests.

Ocular alignment was classified as orthoposition, heterophoria, manifest heterotropia, or intermittent heterotropia. Misalignment was determined as eso, exo and/or vertical. The presence of nystagmus was noted. The evaluation was performed with spectacles if the participant presented with them or without them if the participant was not wearing any correction.

The criteria for referral to the ophthalmologist exam were PVA worse than 0.2logMAR (20/32) in either eye and/or detection of manifest or intermittent strabismus and/or nystagmus. Participants not referred to the ophthalmologist were sent back to the classroom and the parents were reported about the child's healthy visual status and the importance of yearly evaluations.

Ophthalmological exam

Children referred for the complete ophthalmological evaluation have received one drop of tropicamide 1% and one drop of cyclopentolate 1% with an interval of 5 min between them. Pupillary reflexes were evaluated after 30 min from the first drop. Automatized and subjective static (i.e. cycloplegic) refraction, slit lamp examination, and indirect binocular fundoscopy were performed in all participants. Slit lamp examination included eyelid, cornea, conjunctiva, iris and lens evaluation.

Individuals were classified as presenting emmetropia, hyperopia, or myopia according to international guidelines [12–16]. Myopia was defined as spherical equivalent (SE) refractive error of at least −0.50 D and hyperopia as +2.00 D or more. Children were considered myopic if one or both eyes were myopic and hyperopic if one or both eyes were hyperopic, so long as neither eye was myopic.

Statistical analysis

Statistical analyses were performed using Stata/SE Statistical Software, Release 14.0, 2015 (Stata Corp, College Station, Texas, USA). Data cleaning was conducted to verify potential inaccuracies. Frequency tables were used for descriptive analysis. Chi-Square test was used to compare frequencies among groups.

We used the refractive data to calculate the spherical equivalent (SE) through the formula SE = spherical component + (cylindrical component / 2), and it was analyzed on a per-eye basis by multilevel mixed-effects models adjusted for sex and age with a random intercept to account for intra-subject correlation.

The refractive error coverage was calculated considering the ratio of individuals who presented with spectacles and whose PVA was ≥20/40 in the better eye (met need) by the sum of the individuals who presented with spectacles for distance and whose PVA was <20/40 in the better eye improving to ≥20/40 with adequate refraction (undermet need) and those with PVA < 20/40 in the better eye who did not have correction and who improved to ≥20/40 on refraction (unmet need) [10]. Type of refractive error and met/unmet status were evaluated on a per-individual basis by multiple logistic regression analysis. For all tests, P values ≤ 0.05 were considered statistically significant.

$$REC = \frac{met\,need}{met\,need + undermet\,need + unmet\,need}$$

Results

A total of 17,973 children (51.12% females), with ages ranging from 3 to 17 years old [mean ± standard deviation (SD) = 8.24 ± 3.54 years] were included in the study. When considering the total of students aged 3 to 17 years old enrolled in all the CEUs in the city, the study sample represents 22.69% of the total population.

Vision screening

Most children (*N* = 16,661; 92.70%) were not wearing any refractive correction at the moment of the exam. For those using it (*N* = 1,312; 7.30%), the mean spherical equivalent was −1.04 ± 3.00 spherical diopters (SD).

Table 1 shows the ocular alignment status in all the participants at near and distance evaluations.

For both distance and near, most of the participants had orthoposition of visual axes. About one quarter of cases presented a phoria, and most cases were exophoria. Less than 2% presented a tropia; most of which were esotropia. Nystagmus was noted in 55 (0.31%) individuals.

Dynamic automated refraction was performed in 17,783 (98.95%). The mean spherical equivalent was −0.24 ± 1.56 SD (median: 0.00D) and it ranged from −19.75D to +16.00D. The multilevel mixed effects model analysis showed a statistically significant influence of female sex (coefficient: -0.0968; 95%CI: -0.1409 to -0.0527; $p < 0.001$) and older age (coefficient: -0.0876; 95%CI: -0.0938 to -0.0814; $p < 0.001$) on decreasing dynamic automated refraction spherical equivalent. Figure 2 shows the dynamic automated refraction according to sex and age.

A total of 3,645 (20.28%) children were referred for complete evaluation by the ophthalmologist. 3,273 children were referred due to PVA < 20/32 in either eye, 175 due to eye alignment disorders, and 197 due to both reasons.

Ophthalmic examination

Most of the referred children were females (54.49%), and the mean age was 8.93 ± 3.74 (range 3 to 17 years old). Multiple logistic regression for referral showed that girls were more likely to be referred than boys (OR: 1.17; 95%CI: 1.08–1.26; $p < 0.001$), and the odds of being referred increased with age (OR: 1.07; 95%CI: 1.06–1.08; $p < 0.001$).

Out of the total participants referred to the ophthalmologist evaluation, 3,264 (89.55%) performed automated static refraction. Their mean dynamic automated refraction spherical equivalent performed at screening was −1.12 ± 2.90 SD (median: -1.00D), ranging from −20.00D to +16.00D. Their mean static automated refraction spherical equivalent was 0.02 ± 2.64 SD (median: -0.25D), ranging from −24.25D to +15.50D. The multilevel mixed effects model analysis showed a statistically significant influence of age (coefficient: -0.1924; 95%CI: -0.2154 to -0.1694; $p < 0.001$) on increasing static automated refraction spherical equivalent.

Table 1 Ocular alignment status

	Near	Distance
	n (%)	*n (%)*
Orthoposition	13,111 (72.95)	13,114 (72.96)
Heterotropia	227 (1.26)	230 (1.28)
Eso	158 (69.60)	160 (69.56)
Exo	63 (27.76)	63 (27.39)
Vertical	6 (2.64)	7 (3.05)
Heterophoria	4,495 (25.01)	4,480 (24.93)
Eso	1,273 (28.31)	1,268 (28.30)
Exo	3,222 (71.68)	3,212 (71.70)
Vertical	0 (0.00)	0 (0.00)
Intermittent	117 (0.65)	116 (0.64)
Eso	30 (25.64)	29 (25.00)
Exo	87 (74.36)	87 (75.00)
Undetermined	23 (0.13)	33 (0.18)
Total	**17,973 (100.00)**	**17,973 (100.00)**

Figure 3 shows the static automated refraction measured in the evaluation with the ophthalmologist in comparison to the dynamic automated refraction measured at screening, according to age.

A total of 3,434 participants performed static subjective refraction, and the mean spherical equivalent was −0.15 ± 2.56 SD (median: -0.25), ranging from −20.00D to +16.75D. The multilevel mixed effects model analysis showed a statistically significant influence of age (coefficient: -0.1854; 95%CI: -0.2084 to -0.1623; $p < 0.001$) on increasing static subjective refraction spherical equivalent.

Table 2 shows the refractive status classification of participants according to the WHO guidelines.

Overall, 1,370 (7.70%) of participants had myopia, and 577 (3.24%) had hyperopia. Multiple logistic regression showed a statistically significant influence of female sex (OR = 1.13; 95% CI: 1.01–1.27; $p = 0.027$) and older age (OR = 1.17; 95% CI: 1.16–1.19; $p < 0.001$) on myopia diagnosis. For hyperopia, in the other hand, no sex influence was observed ($p = 0.633$) and older age decreased the odds of hyperopia (OR = 0.95; 95% CI: 0.93–0.98; $p < 0{,}001$).

Effective refractive error coverage

The eREC was calculated as the ratio of the 1,102 individuals who presented with spectacles and whose PVA was ≥ 20/40 in the better eye (met need) divided by the sum of these 1,102 individuals plus the 164 individuals who present with spectacles for distance and whose PVA was < 20/40 in the better eye but who improved to ≥ 20/40 on refraction (undermet need) plus the 856 individuals with PVA < 20/40 in the better eye who did not have correction and who improved to ≥ 20/40 on refraction (unmet need). Table 3 shows the results according to sex.

Multiple logistic regression showed a statistically significant influence of age on eREC. Individuals aged 3 to 7 years old are 3.31 times more likely to have an undermet or unmet need than those aged 8 to 12 years old (OR = 3.31; 95% CI: 2.64–4.14; $p < 0.001$), and individuals aged 13 to 17 years old are 1.40 times more likely to have an undermet or unmet need than those aged 8 to 12 years old (OR = 1.40; 95% CI: 1.14–1.71; $p = 0.001$).

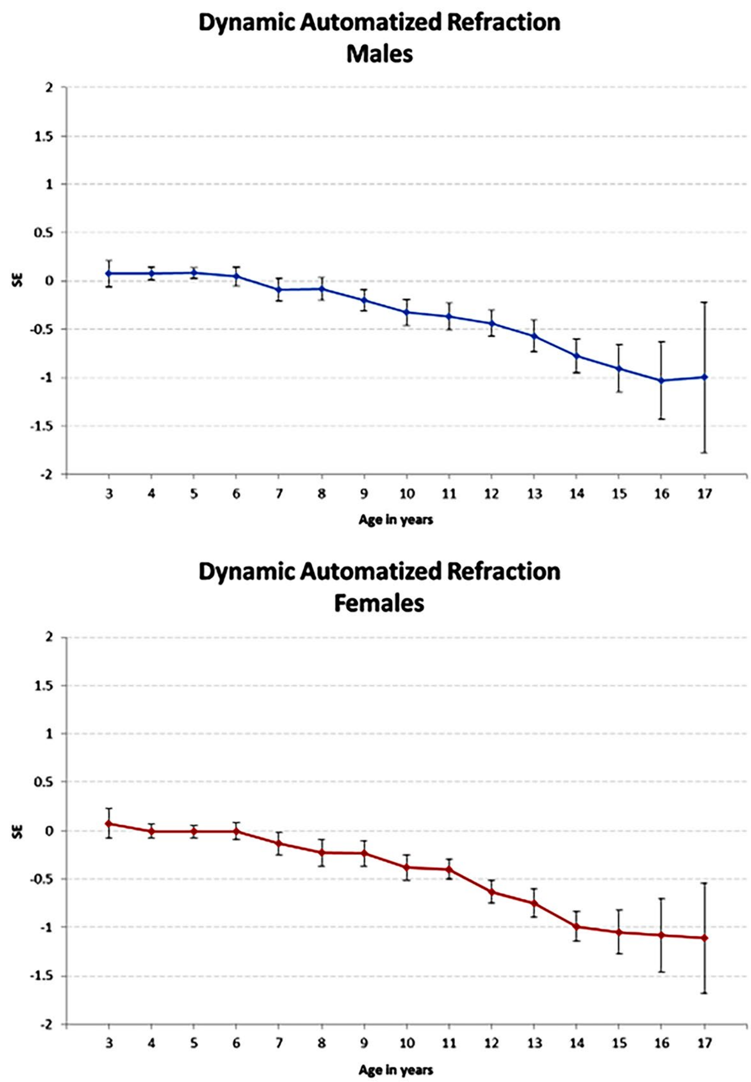

Fig. 2 Mean dynamic automatized refraction in spherical equivalent (SE) according to sex and age. Error bars show respective standard errors

Discussion

Our group evaluated a large population school-aged children from low-income areas of Sao Paulo city, Brazil with visual screening and comprehensive eye exam. Our data showed that most children have eye alignment for both distance and near assessments and that 7.70% presented myopia while hyperopia was observed in 3.24%. We found a low overall eREC of 51.76%, significantly associated with age.

We have previously published a frequency of visual impairment of 14.55% considering PVA which decreased to 1.30% when considering BCVA (best corrected visual acuity) in this population. We also found that 91% of all participants with initial visual impairment in PVA showed improvement after refractive correction provision. In this previous report on frequencies and causes of visual impairment and blindness, we showed that the main causes of vision impairment in this population were uncorrected refractive errors (96.77%), amblyopia (0.88%), and retinal abnormalities (0.37%) [11]. We further explored our data to investigate the refractive status and the effective refractive error coverage (eREC) hereby reported.

Strabismus was diagnosed in 1.28% of the evaluated children, a frequency similar to those observed in previous studies conducted in Brazil (1.40%) [17] and Japan (1.28%) [18]. Our values were lower than those reported in other regions such as Iran (2.02%) [19], United Kingdom (2.40%) [20], Australia (2.80%) [21], Chile (9.86%) [22], and Ethiopia (17.96%) [23]. The variability among regions can be explained by the demographic profile of the population under study in terms of age.

Myopia was observed in 7.70% of participants and was statistically associated with female sex and older age. Previous studies performed in Brazil have shown frequencies of myopia ranging from 5.46% in children

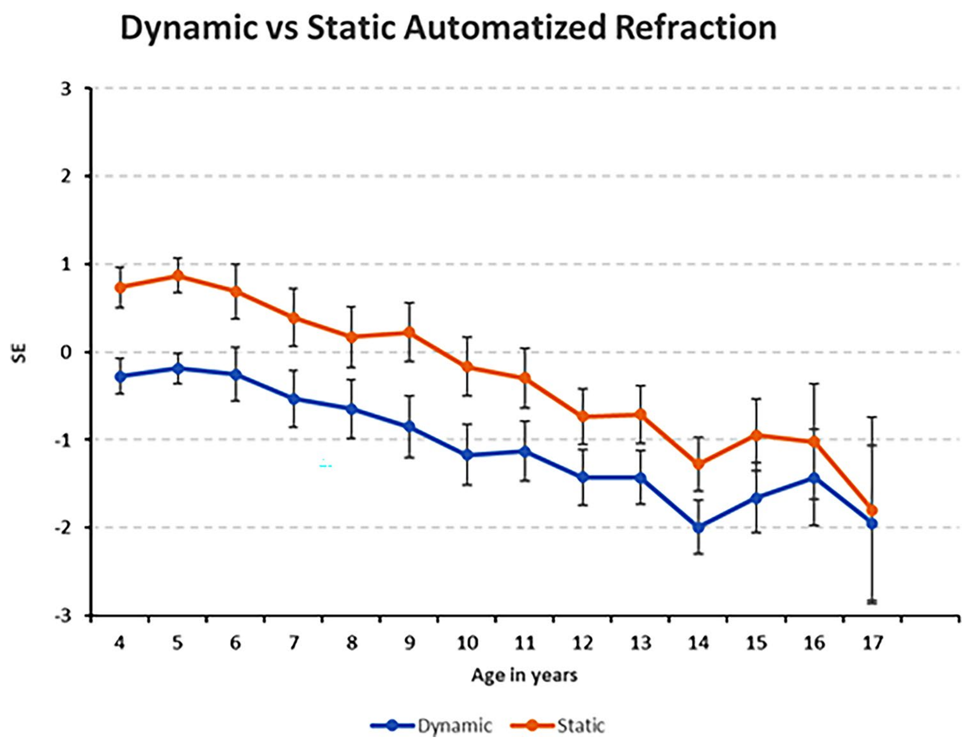

Fig. 3 Dynamic versus static automatized refraction in spherical equivalent (SE) according to age. Error bars show respective standard errors

Table 2 Frequency of refractive status according to WHO guidelines for classification

	Participants who went through subjective refraction N = 3,434	All the participants N = 17,793
	n (%; 95%CI)	n (%; 95%CI)
Emmetropia	1,487 (43.30; 41.65–44.97)	15,846 (90.06; 88.70–91.61)
Myopia	1,370 (39.89; 38.27–41.54)	1,370 (7.70; 7.24–8.02)
Hyperopia	577(16.80; 15.59–18.09)	577 (3.24; 2.96–3.48)

Table 3 Effective refractive error coverage (eREC) by sex and age

	MET	UNDERMET	UNMET	eREC (95% confidence interval)
Sex				
Male	461	68	408	49.20 (46.00 – 53.99)
Female	641	98	453	53.78 (50.93 – 56.59)
Age				
3-7	169	27	328	32.25 (28.37 – 36.39)
8-12	589	83	288	61.35 (58.23 – 64.39)
13-17	344	56	245	53.33 (49.46 – 57.17)
All	**1102**	**166**	**861**	**51.76 (49.63 – 53.88)**

aged 11–14 years old in Sao Paulo to 9.64% in children aged 5–18 years old in Campinas [15, 24]. Global reports reveal a significant variation in myopia prevalence based on geographic location. East Asian countries, including Hong Kong, China, Singapore, and Taiwan, record the highest myopia rates among pediatric populations, with approximately 70–90% affected by age 18 [25]. Recent studies indicate that nearly 60% of children in the United States within this age group experience myopia [26]. In contrast, European and Australian children exhibit lower myopia rates, with 12% of Australian 11- to 15-year-olds, 18% of Irish 12- to 13-year-olds, and 29% of British 12- to 13-year-olds being myopic [27–29]. Our findings align with those observed in Africa, where prevalence remains below 10% [25, 30]. Notably, a separate study found that only 0.8% of Laotian children were myopic, and these rates varied between rural and urban environments [31]. Regardless of the region, myopia has shown a notable increase in prevalence over the past two decades, and the number of individuals affected by myopia globally is expected to rise from 1.4 billion to 5 billion by 2050; when it will affect approximately 50% of the world's population [9].

We found myopia occurrence and magnitude to be associated with age. These findings are in accordance with the literature, and it is likely explained by the eye elongation during the development progress. Previous studies in humans and animal models have shown the natural axial length increase associated with the aging progress [32–34]. Eye growth was found to be considerably slower between ages 12 to 22 years-old (0.04 mm/year) when compared to between ages 6 to 16 years-old (0.12 mm/year) [33]. Recent studies point the influence of light exposure on eye elongation rates and the consequent myopia progression. It has been shown that the light exposure regulates the eye growth due to effects of signaling molecules such as retinal dopamine and retinoic acid [35–37]. In that sense, public health leaders have recommended controlling the number of hours indoors in order to avoid myopia development and progression.

Myopia occurrence and magnitude was also more significantly associated with female sex, which is in accordance with previous reports in the literature [38–40]. Ethoven et al. have recently evaluated a large cohort of children and attributed the differences to social/behavioral aspects such as girls spending less time outdoors, having less sport participation, reading more books and having longer reading times than boys [41]. On the other hand, Xu et al. have shown that most of the myopia differences across sexes are explained by girl's early puberty, considering the hormonal changes and body growth [42]. Further studies comparing biological and behavioral aspects of boys and girls are needed to investigate the underlying reasons for the differences observed.

No global data are available for effective refractive error coverage in children, and there is a pressing need for data collection and reporting in this group [43]. The few individual studies with school-aged children in China and India have shown effective refractive error coverages (eRECs) of 36% and 29%, respectively, which is lower than the 52% observed in the current study [44, 45]. Interestingly, we noticed a significant difference in eREC among different age groups, with children aged 8 to 12 years showing better coverage. This is the age group at which children typically start to have a higher demand for visual tasks in school. Therefore, those in need of refractive correction are more likely to complain to their teachers and parents and, consequently, obtain a recent prescription and spectacles. Conversely, the younger group has the lowest coverage, as children at that age are less likely to complain about visual difficulties and are more likely not to have had an eye examination. Finally, eREC decreases in older age groups, as these children are more likely to have outdated prescriptions.

While the study included a substantial number of tested children, its primary limitation lies in the fact that the data were obtained from a convenience sample which can lead to selection bias and results that are not generalizable to the entire population. Population-based studies require a sampling method to select a group of individuals that are representative of the entire population of interest. However, for rare conditions like childhood visual impairment, achieving the necessary sample size for such studies typically demands a large-scale effort, making them both expensive and time-consuming. Still, this is the most complete study on refractive error profile and refractive error coverage available from a Brazilian group of school children. When interpreting the results, it is also important to take into account that part of the sample was evaluated only by non-cycloplegic automatic refraction which can overestimate myopia and underestimate hyperopia.

In conclusion, most children have shown eye alignment for both distance and near assessments. We observed a frequency of 7.70% of myopia and 3.24% of hyperopia in the evaluated population. Myopia occurrence and magnitude were significantly associated with female sex and older age, while hyperopia occurrence and magnitude were significantly associated with younger age. The overall effective refractive coverage was 51.76% ranging from 32.25% in children aged 3 to 7 years old to 61.35% in children aged 8 to 12 years old. These findings are useful for informing policies and interventions aimed at improving childhood eye health in low-income urban settings. Specifically, public health authorities should focus on targeted eye health programs, early screening initiatives, and the allocation of resources to address the timely detection and correction of refractive errors in this population.

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Author contributions
AGF, RGV, and MC contributed to the study design. RGV, DCG, EPB, and MC contributed to data collection. AGF analyzed the data. AGF wrote the first draft of the report. AGF, RGV, DCG, BGF, EPB, SRS, and MC contributed to the report final version. SRS and MC oversaw the research. The author(s) read and approved the final manuscript.

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Data availability
The data that support the findings of this study are available from the Instituto Verter but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the corresponding author upon reasonable request and with permission of the Instituto Verter.

Declarations

Ethics approval and consent to participate
This study was approved by the H Olhos Institutional Review Boards (#33814120.7.0000.9867) and was carried out in accordance with the tenets of the Declaration of Helsinki. Due to the retrospective design, the informed consent was waived by the Federal University of São Paulo Institutional Review Boards.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Gilbert C, Foster A. Childhood blindness in the context of VISION 2020: the right to sight. Bull World Health Organ. 2001;79(3):227–32.
2. Muhit M, Karim T, Islam J, Hardianto D, Muhiddin HS, Purwanta SA, et al. The epidemiology of childhood blindness and severe visual impairment in Indonesia. Br J Ophthalmol. 2018;102(11):1543–9.
3. Yekta A, Hooshmand E, Saatchi M, Ostadimoghaddam H, Asharlous A, Taheri A, et al. Global prevalence and causes of visual impairment and blindness in children: a systematic review and Meta-analysis. J Curr Ophthalmol. 2022;34(1):1–15.
4. World Health Organization. World report on vision. Geneva: World Health Organization. 2019; Licence: CC BY-NC-SA 3.0 IGO.
5. Cai XB, Shen SR, Chen DF, Zhang Q, Jin ZB. An overview of myopia genetics. Exp Eye Res. 2019;188:107778.
6. Morgan IG, Ohno-Matsui K, Saw SM, Myopia. Lancet. 2012;379(9827):1739–48.
7. Williams KM, Verhoeven VJ, Cumberland P, Bertelsen G, Wolfram C, Buitendijk GH, et al. Prevalence of refractive error in Europe: the European Eye Epidemiology (E(3)) Consortium. Eur J Epidemiol. 2015;30(4):305–15.
8. Vitale S, Sperduto RD, Ferris FL. Increased prevalence of myopia in the United States between 1971–1972 and 1999–2004. Arch Ophthalmol. 2009;127(12):1632–9.
9. Holden BA, Fricke TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. Ophthalmology. 2016;123(5):1036–42.
10. Keel S, Müller A, Block S, Bourne R, Burton MJ, Chatterji S, et al. Keeping an eye on eye care: monitoring progress towards effective coverage. Lancet Glob Health. 2021;9(10):e1460–4.
11. Barbosa EP, Fernandes AG, Viana RG, Salomao SR, Campos M. Vision screening in school children from low-income areas of Sao Paulo city Projeto Ver na Escola: frequency and causes of visual impairment and blindness. Med Res Arch. 2021;9(4):1–11.
12. Murthy GV, Gupta SK, Ellwein LB, Muñoz SR, Pokharel GP, Sanga L, et al. Refractive error in children in an urban population in New Delhi. Invest Ophthalmol Vis Sci. 2002;43(3):623–31.
13. He M, Zeng J, Liu Y, Xu J, Pokharel GP, Ellwein LB. Refractive error and visual impairment in urban children in southern China. Invest Ophthalmol Vis Sci. 2004;45(3):793–9.
14. Robaei D, Kifley A, Rose KA, Mitchell P. Refractive error and patterns of spectacle use in 12-year-old Australian children. Ophthalmology. 2006;113(9):1567–73.
15. Salomão SR, Cinoto RW, Berezovsky A, Mendieta L, Nakanami CR, Lipener C, et al. Prevalence and causes of visual impairment in low-middle income school children in Sao Paulo, Brazil. Invest Ophthalmol Vis Sci. 2008;49(10):4308–13.
16. Cui J, Fu J, Li L, Chen W, Meng Z, Su H, et al. Prevalence and pattern of refractive error and visual impairment among schoolchildren: the Lhasa childhood eye study. BMC Ophthalmol. 2021;21(1):363.
17. Shimauti AT, Pesci Lde T, Sousa RL, Padovani CR, Schellini SA. Estrabismo: detecção em uma Amostra Populacional E fatores demográficos associados [Strabismus: detection in a population-based sample and associated demographic factors]. Arq Bras Oftalmol. 2012;75(2):92–6. Portuguese.
18. Matsuo T, Matsuo C. The prevalence of strabismus and amblyopia in Japanese elementary school children. Ophthalmic Epidemiol. 2005;12(1):31–6.
19. Yekta A, Fotouhi A, Hashemi H, Dehghani C, Ostadimoghaddam H, Heravian J, et al. The prevalence of anisometropia, amblyopia and strabismus in schoolchildren of Shiraz, Iran. Strabismus. 2010;18(3):104–10.
20. Bruce A, Santorelli G. Prevalence and risk factors of Strabismus in a UK multiethnic birth cohort. Strabismus. 2016;24(4):153–60.
21. Robaei D, Rose KA, Kifley A, Cosstick M, Ip JM, Mitchell P. Factors associated with childhood strabismus: findings from a population-based study. Ophthalmology. 2006;113(7):1146–53.
22. Maul E, Barroso S, Munoz SR, Sperduto RD, Ellwein LB. Refractive error study in children: results from La Florida, Chile. Am J Ophthalmol. 2000;129(4):445–54.
23. Agaje BG, Delelegne D, Abera E, Desta K, Girum M, Mossie M, et al. Strabismus prevalence and associated factors among pediatric patients in southern Ethiopia: a cross-sectional study. J Int Med Res. 2020;48(10):300060520964339.
24. Lira RP, Santo IF, Astur GL, Maziero D, Passos TH, Arieta CE. Refractive error in school children in Campinas, Brazil. Arq Bras Oftalmol. 2014;77(3):203–4.
25. Rudnicka AR, Kapetanakis VV, Wathern AK, Logan NS, Gilmartin B, Whincup PH, et al. Global variations and time trends in the prevalence of childhood myopia, a systematic review and quantitative meta-analysis: implications for aetiology and early prevention. Br J Ophthalmol. 2016;100(7):882–90.
26. Theophanous C, Modjtahedi BS, Batech M, Marlin DS, Luong TQ, Fong DS. Myopia prevalence and risk factors in children. Clin Ophthalmol. 2018;12:1581–7.
27. Ip JM, Huynh SC, Robaei D, Kifley A, Rose KA, Morgan IG, Wang JJ, Mitchell P. Ethnic differences in refraction and ocular biometry in a population-based sample of 11-15-year-old Australian children. Eye (Lond). 2008;22(5):649–56.
28. O'Donoghue L, McClelland JF, Logan NS, Rudnicka AR, Owen CG, Saunders KJ. Refractive error and visual impairment in school children in Northern Ireland. Br J Ophthalmol. 2010;94(9):1155–9.
29. Logan NS, Shah P, Rudnicka AR, Gilmartin B, Owen CG. Childhood ethnic differences in ametropia and ocular biometry: the Aston Eye Study. Ophthalmic Physiol Opt. 2011;31(5):550–8.
30. Naidoo KS, Raghunandan A, Mashige KP, Govender P, Holden BA, Pokharel GP, et al. Refractive error and visual impairment in African children in South Africa. Invest Ophthalmol Vis Sci. 2003;44(9):3764–70.
31. Casson RJ, Kahawita S, Kong A, Muecke J, Sisaleumsak S, Visonnavong V. Exceptionally low prevalence of refractive error and visual impairment in schoolchildren from Lao people's Democratic Republic. Ophthalmology. 2012;119(10):2021–7.
32. Fledelius HC, Christensen AS, Fledelius C. Juvenile eye growth, when completed? An evaluation based on IOL-Master axial length data, cross-sectional and longitudinal. Acta Ophthalmol. 2014;92(3):259–64.
33. McCullough S, Adamson G, Breslin KMM, McClelland JF, Doyle L, Saunders KJ. Axial growth and refractive change in white European children and young adults: predictive factors for myopia. Sci Rep. 2020;10(1):15189.
34. Fernandes AG, Alexopoulos P, Burgos-Rodriguez A, Martinez MI, Ghassibi M, Leskov I, et al. Age-related differences in ocular features of a naturalistic Free-Ranging Population of Rhesus macaques. Invest Ophthalmol Vis Sci. 2023;64(7):3.
35. Cohen Y, Peleg E, Belkin M, Polat U, Solomon AS. Ambient illuminance, retinal dopamine release and refractive development in chicks. Exp Eye Res. 2012;103:33–40.
36. Harper AR, Summers JA. The dynamic sclera: extracellular matrix remodeling in normal ocular growth and myopia development. Exp Eye Res. 2015;133:100–11.
37. Brown DM, Mazade R, Clarkson-Townsend D, Hogan K, Datta Roy PM, Pardue MT. Candidate pathways for retina to scleral signaling in refractive eye growth. Exp Eye Res. 2022;219:109071.
38. Li Y, Liu J, Qi P. The increasing prevalence of myopia in junior high school students in the Haidian District of Beijing, China: a 10-year population-based survey. BMC Ophthalmol. 2017;17(1):88.
39. Thorn F, Chen J, Li C, Jiang D, Chen W, Lin Y, et al. Refractive status and prevalence of myopia among Chinese primary school students. Clin Exp Optom. 2020;103(2):177–83.
40. Wang J, Liu J, Ma W, Zhang Q, Li R, He X, et al. Prevalence of myopia in 3-14-year-old Chinese children: a school-based cross-sectional study in Chengdu. BMC Ophthalmol. 2021;21(1):318.
41. Ethoven C. Lifestyle factors in myopia development. Doctoral thesis, Erasmus University, Rotterdam. 2021.
42. Xu R, Zhong P, Jan C, Song Y, Xiong X, Luo D, et al. Sex disparity in Myopia explained by Puberty among Chinese adolescents from 1995 to 2014: a nationwide cross-sectional study. Front Public Health. 2022;10:833960.
43. Bourne RRA, Cicinelli MV, Sedighi T, Tapply IH, McCormick I, Jonas JB, et al. Effective refractive error coverage in adults aged 50 years and older: estimates from population-based surveys in 61 countries. Lancet Glob Health. 2022;10(12):e1754–63.
44. Chin MP, Siong KH, Chan KH, Do CW, Chan HH, Cheong AM. Prevalence of visual impairment and refractive errors among different ethnic groups in schoolchildren in Turpan, China. Ophthalmic Physiol Opt. 2015;35(3):263–70.
45. Gupta V, Saxena R, Vashist P, Bhardwaj A, Pandey RM, Tandon R, et al. Spectacle Coverage among Urban Schoolchildren with refractive error provided subsidized spectacles in North India. Optom Vis Sci. 2019;96(4):301–8.

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