· Investigation ·

Prevalence of refractive errors in children of Puerto Rico

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Abstract

● **AIM:** To determine the prevalence of refractive error in 5- to 17-year-old schoolchildren in Puerto Rico.

● **METHODS:** A quantitative descriptive study of 2867 children aged 5 to 17y from all seven educational regions of Puerto Rico was conducted from 2016–2019. Refractive error was determined *via* static and subjective refraction. Children with distance acuity ≤20/40 or near visual acuity ≤20/32 had a cycloplegic refraction. Data analysis included descriptive statistics, correlation coefficient, Kruskal–Wallis, Chi-square, and *t* test calculations.

● **RESULTS:** Twenty percent of the children had a spherical equivalent refractive error ≤ -0.50 D, 3.2% had a spherical equivalent ≥ +2.00 D, and 10.4% had astigmatism ≥1 D. There was a statistically (but non-clinically) significant myopic change in spherical equivalent refractive error with age ($P<0.001$). The prevalence of myopia increased with age ($P<0.001$) but not hyperopia ($P=0.59$) or astigmatism ($P=0.51$). Males had a significantly higher hyperopic spherical equivalent than females ($P<0.001$). Females had a higher prevalence of myopia ($P<0.001$) than males, but there was no difference in the hyperopia ($P=0.74$) or astigmatism prevalence ($P=0.87$).

● **CONCLUSION:** The prevalence of a spherical equivalent equal to or less than -0.50 D (myopia, 20.7%) is one of the highest among similar-aged children worldwide. Further studies should explore the rate of myopia progression in children in Puerto Rico. Individual children must be monitored to examine the need for treatment of myopia progression.

● **KEYWORDS:** children; refractive error; Puerto Rico; myopia; hyperopia

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INTRODUCTION

Refractive errors, such as myopia, hyperopia, and astigmatism, in children produce retinal image blur and degradation of distance or near visual acuity or both. Uncorrected refractive error is the main cause of visual impairment (49%) and the second most common cause of blindness globally (21%)[1]. Uncorrected refractive error is the main cause of visual impairment in 5- to 15-year-old children worldwide[2]. The prevalence is significantly higher among those with the lowest socioeconomic status and indigenous children[3-4]. Hyperopia and anisometropia in children are associated with deficits in reading performance[5-7]. The provision of eyeglasses to children with refractive error improves their reading and academic performance[8-9]. Low and moderate hyperopia are more prevalent among children with learning difficulties[10-11]. Hearing-impaired children have a higher prevalence of refractive errors[12]. Refractive error is also associated with ocular morbidities[13]. Hyperopia equal to or greater than 2 D is related to strabismus and amblyopia. Uncorrected myopia is associated with asthenopia[14]. High myopia is associated with retinal detachment, myopic macular degeneration, glaucoma, and cataracts. Anisometropias equal to or greater than 3.00 D are associated with a risk for amblyopia in early childhood[15].

The World Report on Vision is a document developed by the World Health Organization that provides evidence on the scope of the eye and visual conditions at a global level, calls attention to efficient approaches to eye care, and makes actionable suggestions to enhance eye care services[16]. The report's main recommendation is that all nations offer integrated, patient-centered eye care services[17]. One of the core strategies for improving the quality of and access to eye care is the collection of clinical data on the prevalence of refractive errors. These data provide the basis for sound health policies and actions[18]. Refractive error studies in children are particularly critical given the increasing prevalence of myopia worldwide[9]. The identification of myopic children will allow the use of refractive and pharmacological procedures to slow down the progression of myopia[19-20].

Refractive error in children (RESC) studies have been conducted worldwide, including in Africa, China, India, Nepal, Ethiopia, Iran, Northern Ireland, Pakistan, Chile, and Mexico, among others. These studies have found significant differences in the prevalence of refractive error in children across different nations and ethnic groups[21].

Puerto Rico is a Caribbean country with 3.3 million people[22]. Its population is of mixed European, Indian, and African ancestry[23]. Given the relationship between genetics and refractive error, particularly myopia, refractive studies in the population living on the island are particularly important.

Only two studies have addressed the refractive errors of persons living in Puerto Rico. One early study included 1109 persons living in a rural community, of whom 366 were children[24]. A second recent retrospective study of residents of Puerto Rico attending a university clinic included adults from 40 to 89 years of age[25]. There is a lack of studies addressing the prevalence of refractive errors in children in Spanish-speaking Caribbean countries, including Puerto Rico, using an examination protocol and refractive error definitions that can be compared with studies in other nations and regions[26].

This is the first study to explore the prevalence of refractive errors among an island-wide sample of 5- to 17 years old from all educational regions of Puerto Rico.

SUBJECTS AND METHODS

Ethical Approval The project received the approval of the university ethics board and the research review board of the Department of Education of Puerto Rico (approval No.15-16-060). The parents of the children received an informed consent form to permit their child's participation in the study.

The study is a quantitative descriptive study of refractive errors in school children in Puerto Rico. The sample included 2867 children aged 5 to 17y from 30 schools in the 7 school districts of the Commonwealth of Puerto Rico. A total of 1432 children (49.9%) were male, and 1435 (50.1%) were female. At least 1 elementary, intermediate, and high school were chosen at random from each district by the Director of the Health Nursing Services of the Department of Education of Puerto Rico. Each school had a maximum of 300 children. Once a school was selected, all the children within that school were eligible to participate.

Procedure Each school was visited in advance 1mo before the scheduled examinations for that institution to discuss the project's goals with the school principal and nurse. Consent forms were distributed to each individual teacher. During that visit, we selected an appropriate space within the school that could accommodate the necessary equipment, examination stations, and examination personnel.

The examination personnel who visited each school included 2 or 3 licensed optometrists and 6 to 8 advanced optometry students who worked under the supervision of optometrists from the Inter American University of Puerto Rico School of Optometry. All examination personnel were trained on the protocol of the study. Each school required 2 to 4 visits to examine all the children. For each child whose parent(s) or guardian(s) consented to their participation, a description of the testing procedure was provided. Each child was asked to give their consent to participate. The examinations at the 30 schools started in August 2017 and ended in December 2019.

The examinations followed closely the protocol recommended for refractive error studies in children by the World Health Organization[26]. The distance visual acuity criterion of 20/40 provides optimum sensitivity and specificity for myopia but not hyperopia. Therefore, those who had near visual acuity of 20/32 or worse also received a cycloplegic exam to assess hyperopia more effectively[27].

Distance (6 m) and near (40 cm) unaided visual acuity values were obtained for the right and left eyes of each child with the standard logarithm of the minimum angle of resolution (logMAR) charts. Static and subjective refraction were conducted with portable phoropters. The phoropter had spherical ranges from -20 D to +20 D and cylindrical ranges from -0.25 D to -6.00 D. All refractions were conducted by licensed optometrists who belonged to the faculty of the Inter American University of Puerto Rico School of Optometry and members of the examination team using standard refractive techniques[28]. Cycloplegic refraction was performed in children whose unaided distance visual acuity was 20/40 or worse ($\geq$0.3 logMAR) and/or whose near visual acuity was 20/32 or worse ($\geq$0.2) in either eye. To induce cycloplegia, we administered 1 drop of proparacaine hydrochloride 0.5% in each eye. After 2min, 2 drops of 1% cyclopentolate hydrochloride with an interval of 5min were administered in each eye[16,18,26,28]. To classify the type of refractive error, we used the spherical equivalent classification for population-based studies based on the World Health Organization recommendations[29-38].

Based on the spherical equivalent refractive error (sphere +0.5 cylinder), myopia was defined as a spherical equivalent equal to or less than -0.50 D. Hyperopia was defined as a spherical equivalent equal to or higher than +2.00 D. Astigmatism was defined as a cylinder magnitude equal to or more than 1 D.

Statistical Analysis We used Chi-square tests of independence to determine the relationships of the prevalence of myopia, hyperopia, and astigmatism with age. Independent samples t-tests were used to compare the prevalence of refractive errors between males and females. Since the distribution of refractive errors was nonnormal, we used the Kruskal-Wallis test to determine the significant differences in the spherical equivalent refractive error by age[39]. We compared the prevalence of refractive errors in our study to those in other studies using the binomial test with weighted data. Statistical analyses were conducted with IBM SPSS© version 28 software[40].

RESULTS

The bivariate Pearson correlation coefficient between the spherical equivalent of the right and left eye was 0.88 [95% confidence Interval (CI) 0.87-0.89, P<0.001]. Therefore, we considered the right eye results representative of the refractive error in each participant and analyzed only the right eye in the statistical analyses.

Distribution of Children by Sex and Age There were a total of 1432 males (49.9%) and 1435 females (50.1%). The mean age was 10.9y, and the median age was 11.2±3.46y. The median age of males was 12y, and the median age of females was 14y. Table 1 shows the distribution of children by age and sex.

Spherical Equivalent Refractive Error by Age The mean spherical equivalent refractive error showed a myopic shift from 5 to 16-17y of age (Figure 1). We analyzed the distribution of refractive error by age with the Kruskal–Wallis nonparametric test. The data followed all the assumptions of this test: one dependent variable (spherical equivalent of the refractive error), independent groups defined by age, independence of observations, and same variability of the independent variables. Since we conducted multiple comparisons between the age groups, we used Dunn's procedure with the Bonferroni correction[39,41]. Although multiple comparisons may result in the relative loss of statistical power, the results showed statistically significant differences in the spherical equivalent refractive error among the different age groups (5 to 17 years old), $\chi^2(12)=55.63$, P<0.001. Post hoc pairwise comparisons showed significant differences ($P\leq0.05$) in the spherical equivalent refractive errors among several age groups. The spherical equivalent in the 5-year-old group was significantly higher (more hyperopic) than those in the 14- to 17-year-old groups. The spherical equivalent in the 7-year-old group was significantly higher (more hyperopic) than those in the 15- and 16-year-old groups. The spherical equivalent in the 16-year-old group was significantly lower (more myopic) than those in the 7- to 9-year-old groups and the 12-year-old group. The maximum difference between age groups was 0.65 D (between the 5-year-old and the 16- and 17-year-groups).

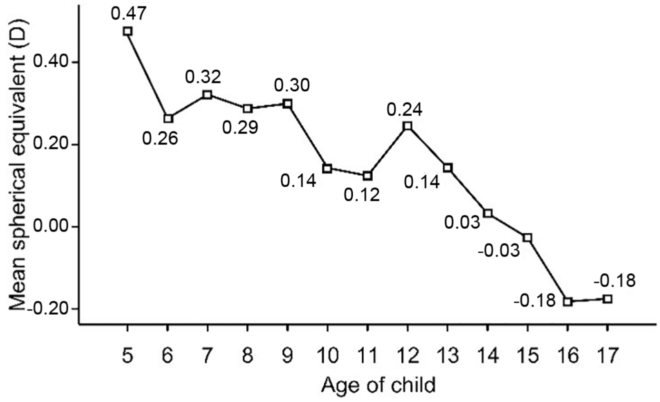

Figure 1 Mean spherical equivalent of the refractive error (diopters) by the age of the child (years) in a sample of school children in Puerto Rico.

Table 1 Distribution of children by age and sex *n* (%)

Age	Male	Female	Total
5	111 (7.8)	82 (5.7)	193 (6.7)
6	103 (7.2)	72 (5.0)	175 (6.1)
7	108 (7.5)	87 (6.1)	195 (6.8)
8	103 (7.2)	107 (7.5)	210 (7.3)
9	113 (7.9)	81 (5.6)	194 (6.8)
10	90 (6.3)	71 (4.9)	161 (5.6)
11	89 (6.2)	95 (6.6)	184 (6.4)
12	153 (10.7)	166 (11.6)	319 (11.1)
13	175 (12.2)	171 (11.9)	346 (12.1)
14	172 (12.0)	184 (12.8)	356 (9.2)
15	100 (7.0)	163 (11.4)	263 (5.0)
16	70 (4.9)	72 (5.0)	142 (5.0)
17	45 (3.1)	84 (5.9)	129 (4.5)
Total	1432 (100.0)	1435 (100.0)	2867 (100.0)

Prevalence of Myopia, Hyperopia, and Astigmatism A total of 20.7% (95%CI 19.2% to 22.2%) of the children had a spherical equivalent equal to or less than -0.50 D. A total of 3.2% (95%CI 2.6% to 3.9%) had a spherical equivalent equal to or greater than +2.00 D. Approximately 1 of every 4 children (23.8%, 95%CI 22.3%-25.4%) met the myopia or hyperopia refractive error criteria. A total of 10.4% (95%CI 9.3% to 11.5%) of the children had astigmatism equal to or greater than 1.00 D.

The prevalence of myopia, hyperopia, and astigmatism by age group is shown in Table 2. There was a significant association between the prevalence of myopia and age [$\chi^2(12, n=2867)=68.2$, P<0.001], with higher prevalence rates in the 14- to 17-year-old groups than in the 5- to 8-year-old groups.

Refractive Error and Sex Males had a mean spherical equivalent refractive error of +0.23 D, while females had a mean spherical equivalent of +0.08 D (95%CI: 0.06 to 0.22); the difference was statistically significant [$t(2865)=3.40$, P<0.001). Females had a significantly higher prevalence of myopia (23.3%) than males (18.0%; t=3.58, df=2840, P<0.001). There was no significant difference in the prevalence of hyperopia between males (3.3%) and females (3.0%, t=0.33, df=2865, P=0.74). There was also no significant difference in the prevalence of astigmatism between males (10.3%) and females (10.5%; t=0.165, df=2865, P=0.87).

Table 2 Prevalence of myopia, hyperopia, and astigmatism by age *n* (%)

Age (*n*)	Myopia[a]	95%CI	Hyperopia[b]	95%CI	Astigmatism[c]	95%CI
5 (193)	18 (9.3)	5.9-14.3	9 (4.7)	2.4-8.8	16 (8.3)	5.1-13.1
6 (175)	33 (18.9)	13.7-25.3	7 (4.0)	1.8-8.2	19 (10.9)	7.0-16.4
7 (195)	25 (12.8)	8.8-18.3	4 (2.1)	0.6-5.3	15 (7.7)	4.6- 12.4
8 (210)	36 (17.1)	12.6-22.9	11 (5.2)	2.9-9.2	24 (11.4)	7.8-16.5
9 (194)	36 (18.6)	13.7-24.7	9 (4.6)	2.3-8.7	21 (10.8)	7.1-16.1
10 (161)	27 (16.8)	11.7-23.4	6 (3.7)	1.5-8.1	21 (13.0)	8.6-19.2
11 (184)	44 (23.9)	18.3-30.6	4 (2.2)	0.65-5.7	14 (7.6)	4.5-12.5
12 (319)	63 (19.7)	15.7-24.5	9 (2.8)	1.4-5.4	30 (9.4)	6.6-13.1
13 (346)	57 (16.5)	12.9-20.8	8 (2.3)	1.1-4.6	31 (9.0)	6.4-12.5
14 (356)	96 (27.0)	22.6-31.8	9 (3.1)	1.7-5.5	39 (11.0)	8.1-14.7
15 (263)	69 (26.2)	21.3-31.9	8 (3.0)	1.5-6.0	34 (13.0)	9.4-17.6
16 (142)	47 (33.1)	25.9-41.2	2 (1.4)	0.1-5.3	14 (9.9)	5.9-16.0
17 (129)	41 (31.8)	24.4-40.3	3 (2.3)	0.49-6.9	19 (14.7)	9.6-21.9
Total (2867)	592 (20.7)	19.2-22.2	91 (3.2)	2.6-3.9	297 (10.4)	9.3-11.5

n: Number of children by age and refractive error. 95%CI: 95% confidence interval of percent prevalence. [a]$P<0.001$, Chi-square test for myopia and age; [b]$P=0.59$, Chi-square test for hyperopia and age; [c]$P=0.51$, Chi-square test for astigmatism and age. There was no significant association between hyperopia and age [$\chi^2(12, n=2867)=10.34$, $P=0.59$] or astigmatism and age [$\chi^2(12, n=2867)=11.22$, $P=0.51$].

DISCUSSION

The spherical equivalent refractive error showed a significant decreasing trend toward myopia with age. This trend was also observed in Africa, China, Ethiopia, Iran, Northern Ireland, and India studies[3,29-31,33-34,37-38,42-47]. The trend is driven by an increase in the prevalence of myopia with age. Although statistically significant, the largest difference in the refractive error was less than 0.65 D, which is not clinically significant.

Approximately 1 out of 5 children (20.7%) were myopic. This prevalence was significantly higher ($P<0.001$) than those in studies that used similar refractive criteria and age ranges from the Shunyi District of China (14.6%), Yongchuan District of China (13.8%), Sweden (10.0%), Somalia (9.1%), Nepal (9.0%), Ghana (6.9%), Chile (6.9%), India (5.3%), Bangladesh (5.8%), Ethiopia (4.1%), South Africa (2.9%), and Pakistan (2.3%) but significantly lower ($P<0.001$) than Indonesia (32.7%), Paraguay (37.7%), Saudi Arabia (40.8%), Nigeria (46.4%), Eastern China (63.1%), and Malaysia (64.3%)[29,31-34,36,48-58]. Globally, the highest prevalence of myopia at 15 years of age occurs among East Asians (69%), and the lowest prevalence occurs among Africans (4.7% to 5.5%; 5.5%)[59-60]. The prevalence of myopia among 15-year-old children in our study was 26.2%. The highest prevalence of myopia equal to or less than -0.50 D in Latin America was found by Villareal among 1035 12- and 13-year-old Mexican children (44%). The prevalence in the study by Villareal was significantly higher than the overall prevalence among 12- to 13-year-old children in our study (18.0%, $P<0.001$)[61].

Rodriguez and Romero[25] analyzed the clinical records of adult patients (40 to 89 years of age) attending a university optometric clinic in Puerto Rico. Using the same criteria for myopia (spherical equivalent ≤ -0.50 D), they found a prevalence of myopia of 14.7%, which is significantly lower than the overall prevalence of 20.7% of the children in our study ($P<0.001$). This trend of a higher prevalence of myopia in children than adults in a sample of Puerto Rican subjects was also found by Gordon[24] in 1990 in a rural population of residents of Puerto Rico that included 366 children up to 20 years of age. Gordon[24] found a prevalence of myopia equal to or greater than -0.50 D of 13.1%, significantly lower than our prevalence ($P<0.001$). Our higher prevalence of myopia suggests that the prevalence of myopia in children of Puerto Rico has increased during the approximately 30y between the two studies. Trend studies show that the prevalence of myopia is increasing worldwide, up to 23% per decade among East Asians[59,62].

Approximately 1 of every 30 children (3.2%) was hyperopic. The prevalence of hyperopia in the present study was significantly higher ($P<0.001$) than the prevalence in Yangxi County of China (1.2%), Shunyi District of China (2.0%), South Africa (1.8%), Pakistan (2.3%), Mexico (2.4%), and Somalia (2.7%)[29-31,36,63]. It was not significantly different ($P=0.424$) from the prevalence in Paraguay (3.9%), the Yongchuan District of China (3.3%), and Bangladesh (2.6%)[33,52,57], and it was significantly lower ($P<0.001$) than the prevalence in India (4.0%), Nigeria (17.5%), Iran (16.6%), Ghana (17.5%), and Chile (21.6%)[32,37,48,50,64]. Rodriguez and Romero[25] found a prevalence of 6.8% of hyperopia equal to or greater than 3.25 D among adults in Puerto Rico. This higher prevalence of hyperopia among adults compared with older children has been found in other studies[65].

The Gordon is study[24] found a prevalence of 1.6% of hyperopia equal to or greater than 2.25 D in their sample of 366 young subjects up to 20y of age, significantly lower than our prevalence of 3.2% (P=0.002) for hyperopia equal to or greater than 2 D. The study was conducted nearly two decades ago, used a smaller sample of children, and had a slightly higher hyperopia criterion. The refractions were conducted without cycloplegia, which may explain this difference.

Nearly 1 of every 10 children (10.4%) was astigmatic. This prevalence was not significantly different from 10.3% in a sample of 3- to 18-year-old children in India (P=0.47) but was higher than the prevalence of 4.2% among schoolchildren in Nepal (P<0.001)[49,66]. The prevalence in the present study was significantly lower (P<0.001) than the prevalence in 4- to 6-year-old children in China, 7- to 15-year-old children in Taiwan (14.8%) and the prevalence in a sample of 7- to 9-year-old children in Singapore (19.2%)[67-69]. A study on indigenous children in the United States showed a high prevalence of astigmatism (42%) equal to or greater than 1 D[70]. Neither Gordon[24] nor Rodriguez and Romero[25] segregated subjects by degrees of astigmatism, so no comparison is possible between their study and ours. Given the mixed indigenous ancestry of Puerto Ricans, further studies may clarify whether astigmatism in the pediatric population is associated with their indigenous genetic composition[23].

Based on the spherical equivalent, females were less hyperopic than males, although the difference was not clinically significant (0.14 D). This difference can be explained by the higher prevalence of myopia (≤-0.50 D) in females. A higher prevalence of myopia in females has been found in Yangxi County, China; Sunyi District, China; Mexico; India; and a multiethnic study in the United States[30-31,61,71-72]. Global estimates indicate a higher prevalence of myopia in adolescent females than in males among East Asians and Whites[59] Some studies found a higher prevalence of hyperopia among females in Chile, Mopani District, South Africa, and young children in California, United States[46,48,73]. Other studies have found no difference between the sexes in Ethiopia, South Africa, Iran, Northern Ireland, and Nepal[34,36,38,74]. A study of adults in Puerto Rico reported no difference in the prevalence of myopia, hyperopia, and astigmatism between males and females[25].

The prevalence of myopia (SE≤-0.50 D) significantly increased with the children's age. This trend toward myopia in older children has been observed in other studies[64,75-77]. The mean prevalence of myopia in 14- to 17-year-old was approximately 1.7 times higher than that in 5- to 14-year-old (Table 2). The prevalence of hyperopia (SE≥+2 D) and astigmatism (≥1 D) did not significantly increase with age.

One limitation of our study is the approximately 12% decrease in the number of school-aged children in Puerto Rico in the last 3y, mainly due to migration to the continental United States. Thus, the prevalence results may be influenced by the recent decrease in the number of children[78].

A second limitation is using cycloplegia only in children with distance visual acuities equal to or worse than 20/40 (as conducted in RESC studies) or near visual acuity worse than 20/32. The best determination of refractive error, in particular hyperopia, is achieved by controlling accommodation through cycloplegia in all children[15]. In our study, the research review board of the Department of Education of Puerto Rico approved cycloplegia only in children failing the distance or near visual acuity criteria.

In conclusion, the prevalence of myopia in our sample of school children is one of the highest worldwide. Globally, myopia prevalence is increasing rapidly. Therefore, follow-up prevalence studies should assess how fast the myopia trend is changing in school children on the island of Puerto Rico. Myopia progression can be slowed through refractive and pharmacological treatment options such as multifocal eyeglasses, multifocal contact lenses, orthokeratology, and low-dose atropine[20,79]. Eye care professionals are responsible for examining these children and initiating treatment to achieve myopia progression control when warranted.

Although the prevalence of hyperopia was significantly lower than the prevalence of myopia, hyperopia has the greatest potential to impact learning in children[6-7,15]. All children should undergo cycloplegic refraction to properly diagnose this type of refractive error.

In addition to distance visual acuity, we recommend that refractive error studies incorporate near visual acuity as a criterion for cycloplegic refraction to accurately determine the prevalence of hyperopia in children[15]. National eye care programs for children should not be limited to vision screening services that have limited sensitivity and specificity[80]. These programs must promote parents' awareness of and access to primary eye care services, including comprehensive eye exams and eyeglasses[81]. The effectiveness of these strategies has been demonstrated in improving the academic performance of school children[82].

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