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Refractive status in a German pediatric cohort: A cross-sectional Analysis of the LIFE Child data

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Abstract

Purpose. Current prevalence rates of myopia in children and adolescents vary all over the world, with especially high prevalence rates in East Asian countries. The objective of this study was to describe the refractive status in children and adolescents growing up in Germany.

Material and Methods. Non-cycloplegic refractive status of children of the LIFE Child study in Leipzig, Germany, was measured by wavefront-based autorefraction in 1934 subjects (925 girls / 1009 boys), aged 3 to 16 years (mean = 9.05 ± 3.91). Myopia was defined as spherical equivalent refractive error (SE) ≤ -0.75 diopters (D), emmetropia as -0.75 D > SE < +0.75 D, hyperopia as SE ≥ +0.75 D and astigmatism as cylinder ≤ -0.75 D. Anisometropia was defined as a difference of ≥ 1.0 D in the SE between the two eyes.

Results. Analysis revealed that refractive error became more myopic with older age (b = -0.08, p < 0.001), with an observed prevalence of myopia of 27 % in 16-year-old children (4 % in 3-year-olds). The true prevalence of myopia might be lower as non-cycloplegic measurements might overestimate refractive error in myopes and underestimate refractive error in hyperopes which in turn may overestimate the prevalence of myopia. The prevalence of anisometropia also increased with growing age (OR = 1.14, observed prevalence in 3- versus 16-year-olds = 2.3 % and 8.1 %, respectively). The prevalence of astigmatism was 11.8 %.

Conclusion. Myopia prevalence in German children aged 3 to 16 years is around or even less than 10 %, taking into consideration that measurements were carried out without cycloplegia. Our results are comparable to other European paediatric studies. In comparison to East-Asian countries myopia prevalence, and thus the risk for eye diseases related to high myopia, is much lower in Germany.

Keywords

Myopia, prevalence, refraction, anisometropia, astigmatism, hyperopia

Introduction

Uncorrected refractive error is the most common cause for moderate or severe distance vision impairment worldwide and the second leading cause of blindness.[1] Myopia in older adults is related to an elevated risk for glaucoma,[2] myopic maculopathy[3] and cataract.[4] High myopia increases the risk of pathologic ocular changes, such as retinal detachment.[5] Hyperopia, in contrast, is associated with higher proportions of strabismus and anisometropia in children.[6] Both are common causes of amblyopia.

Besides, visual impairment due to uncorrected myopia causes massive economic burdens worldwide. Naidoo et al.[7] estimated the global potential productivity loss from uncorrected myopia at US$ 244 billion. Moreover, Holden[8] predicted that in 2050, 49.8 % of the world population will be myopic and 9.8 % will have high myopia, respectively. Consequently, the already high costs might increase steadily.

Comparison of different data regarding the prevalence of myopia in childhood is difficult due to different age groups, varied refractive measurement methods (for example, the use of cycloplegia) and variability in the definition of myopia. Current prevalence rates of myopia vary all over the world. In children and adolescents aged 5 to 15 years, who underwent cycloplegic autorefractometry, myopia (SE ≤ -0.5 D) was observed in 2.6 % in Iran,[9] whereas in China,[10] 36 % of participants were reported to be myopic.

So far, limited data have been published for Europe and notably Germany. In Poland,[11] 13.3 % of participants aged 6 to 18 years were reported to be myopic whereas children and adolescents between 12 and 13 years living in Sweden[12] showed prevalence rates of 49.7 %. In the UK, the prevalence of myopia in 6- to 20-year-old children was reported to range between 2 % in the youngest and 19 % in the oldest children.[13] Käsmann-Kellner et al.[14] published 1998 myopia prevalence rates of 8 % in German kindergarten children using retinoscopy without cycloplegia. Nearly 20 years later, the KiGGS study, a nationwide, population-based health survey in Germany, found a prevalence of myopia of 13.3 % in children and adolescents aged 3 to 17 years.[15] However, in this survey, status of myopia and the use of spectacles were reported by parents. It needs to be taken into account that parents are not always able to distinguish between myopia and hyperopia. The result of the KiGGS study is similar to the findings of another German study, which reported a myopia prevalence rate of 11.9 % in children and adolescents aged 2 to 17 years.[16] The authors used data about refractive correction based on self- or parent-reported information of prescribed spectacles. However, also children without spectacles might have ametropia. Furthermore, ophthalmologists might differ in their criteria or cut-offs for prescribing spectacles.

The present study aimed to describe the distribution of refractive status depending on age and sex based on objective wavefront-based autorefraction measurements in a large cohort of German children and adolescents.

Materials and Methods

Participants

Data were collected during the period of January 2014 to May 2018 in the LIFE Child study center in Leipzig, Germany. The LIFE Child study (clinical trial number NCT02550236) is a longitudinal childhood cohort study aiming to investigate healthy child development and the development of civilization diseases.[17,18] Participants mainly originate from the city of Leipzig and surrounding areas are recruited via advertisement at different institutions, such as schools and public health centers between birth and 18 years of age. All families interested in the study are invited to participate voluntarily. Children suffering from any chronic, chromosomal, and syndromal diseases are excluded. Subsequent visits are scheduled every year.

Informed written consent was provided by all parents before the inclusion of their children in the study. The study was conducted in accordance with the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of the Medical Faculty of the University of Leipzig (Reg. No. 264/10-ek).

For the present study, baseline measurements of 3 to 16 year old children and adolescents (n = 1934) were analyzed.

Examination procedures

Noncycloplegic refractive status of each eye (3 mm pupil diameter and 12 mm vertex distance) was measured three times using a wavefront-based autorefractor (ZEISS i.Profiler plus, Carl Zeiss Vision GmbH, Aalen, Germany). Uncorrected distance monocular logMAR visual acuity was determined according to a detailed standard operating procedure by a team of three experienced optometrists using logMAR charts (ZEISS i.Polatest, Carl Zeiss Vision GmbH, Aalen, Germany) at 6 m distance. Ambient room lighting and single line letters were used. For children who were not able to read letters, line or single Kolt-test optotypes were presented. A line was passed, if three out of five optotypes were read correctly. At every eye examination, past or present eye diseases were documented. The measurement of cycloplegic refractive status was rejected by the Ethics Committee and, therefore, not applied in this study.

Definition of refractive errors

Refractive data were converted to the spherical equivalent (SE = sphere + cylinder ÷ 2). For each child, we selected the median SE measurement of the three measurements and used the respective SE and cylinder values for all further analyses. In young population non-cycloplegic autorefraction might show a myopic shift in refractive error due to excessive residual accommodation.[19] This bias might lead to an overestimation of myopia or an underestimation of hyperopia. Based on grouping for non-cycloplegic refraction in a systematic

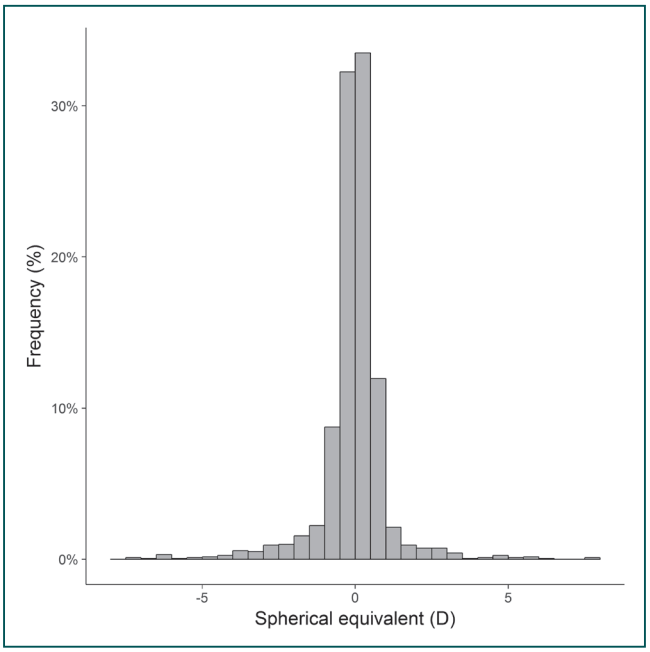

Fig. 1: Refractive error distribution in the total population (n = 1934) expressed as spherical equivalent.

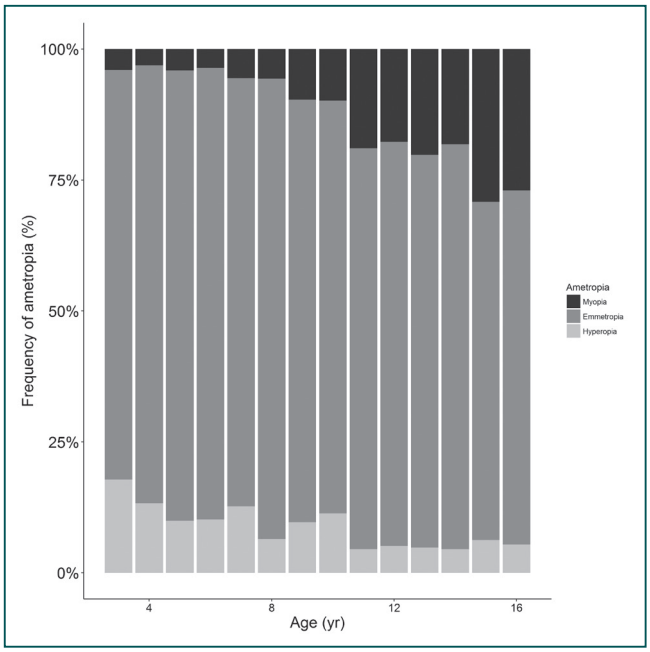

Fig. 2: Prevalence of emmetropia, myopia and hyperopia in relation to age.

review by Hashemi[20] and a recommendation by the International Myopia Institute[21], we used the following definition for refractive error: myopia: SE ≤ -0.75 diopters (D); emmetropia: -0.75 D > SE < +0.75 D; hyperopia: SE ≥ +0.75 D and astigmatism ≤ -0.75 D. Anisometropia was defined as a difference of ≥ 1.0 D in the SE between the two eyes.[22]

Data analysis

All analyses were conducted using R, version 3.3.4. The Kolmogorov-Smirnov-Test was used to test the difference of the distributions of the SE of left and right eyes, as well as to test whether the SE was normally distributed. Spearman correlation analysis was conducted to assess the relationship between SE or anisometropia and age and Mann-Whitney-U-Test was performed to investigate gender differences. Logistic regression was used to examine odds ratios (OR) to assess associations between the prevalence of myopia, emmetropia, hyperopia or anisometropia and age. Possible relations between prevalence of refractive status and gender were tested by χ^2 tests. The significance level alpha was set to 0.05. Detailed analyses were carried out on the right eye for all participants.

Results

Myopia, emmetropia and hyperopia

The sample consisted of 1934 children and adolescents (925 girls, 1009 boys, mean age = 9.1 years; SD = 3.9). Information on the socio-economic status of the family, which

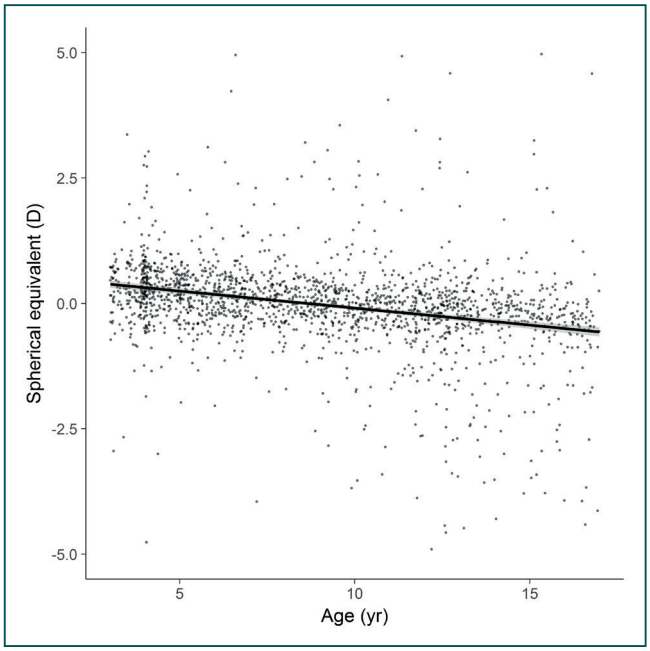

Fig. 3: Spherical equivalent as a function of age (r = 0.37, p < 0.0001).

were self-reported by the parents, was available in 1833 children (95 %). Of these children, 11 % belonged to the low, 57 % to the middle, and 33 % to the high social stratum. Compared to a large representative sample, this distribution indicated a slight underrepresentation of the low social stratum.[23]

The mean SE of all 1934 children and adolescents was -0.03 D (SD = 1.13 D) for the right eyes and -0.04 D (SD = 1.13 D) for the left eyes. There was no significant difference in the distribution of SE between left and right eyes

Table 1: Prevalence of myopia, emmetropia, hyperopia, anisometropia and astigmatism among children of 3 to 16 years of age, stratified by age.

Age (yr)	Participants (n)	Myopia (%)	Emmetropia (%)	Hyperopia (%)	Anisometropia (%)	Astigmatism (%)
		SE ≤ -0.75 D	-0.75 D > SE ≤ +0.5 D	SE ≥ +0.5 D	difference of SE ≥ 1.0 D	≤ -0.75 D
3	174	4.0	78.2	17.8	2.3	10.9
4	226	3.0	83.6	13.3	2.2	15.6
5	171	4.0	86.0	9.9	2.9	9.9
6	167	3.5	86.2	10.2	1.8	10.2
7	126	5.6	81.7	12.7	2.4	9.5
8	124	5.6	87.9	6.5	0	8.1
9	145	9.7	80.7	9.7	2.1	8.3
10	132	9.8	78.8	11.4	6.1	15.9
11	132	18.9	76.5	4.5	5.3	8.3
12	175	17.7	77.1	5.1	5.1	9.7
13	104	20.2	75.0	4.8	2.9	12.5
14	88	18.2	77.3	4.5	4.5	12.5
15	96	29.2	64.6	6.3	11.5	19.8
16	74	27.0	67.6	5.4	8.1	20.3
Total	**1934**	**10.8**	**79.8**	**9.4**	**3.7**	**11.8**

(p = 0.95). For more accessible illustration, the following findings describe right eyes only.

The SE of all children and adolescents, ranging from -7.36 D to +9.05 D, was not normally distributed (p < 0.0001). There were more individuals with a SE above the mean than below (1044 vs. 890 individuals, see Fig. 1). Overall, in 79.8 % of the children and adolescents emmetropia was found. Myopia was prevalent in 10.8 % (mean SE: -2.06 D ± 1.43 D) and hyperopia in 9.4 % (mean SE: +1.82 D ± 1.46 D). The prevalence rates of refractive status per year of age are presented in Table 1. Our data showed a higher prevalence of myopia (OR = 1.24, p < 0.0001) and a lower prevalence of hyperopia (OR = 0.90, p < 0.0001) with older age. The prevalence of emmetropia was also lower with older age (OR = 0.93, p < 0.0001, see Fig. 2). At the age of 3 years, 4.0 % of the participants were myopic, 78.2 % emmetropic, and 17.8 % hyperopic. At the age of 16 years, in contrast, 27.0 % were myopic, 67.6 % were emmetropic, and 5.4 % were hyperopic. A gender difference in the prevalence of myopia, emmetropia and hyperopia was not observed (χ^2 = 0.70, p = 0.71). Also, the distribution of myopia, emmetropia, and hyperopia did not differ significantly in children from the low, middle, or high social stratum (χ^2 = 0.70, p = 2.70, p = 0.61).

Fig. 3 shows the distribution of SE by age and the respective regression line. There was a small negative correlation between age and SE (R^2 = 0.14, p < 0.0001). With older age, the average refractive error was more myopic. At the age of 3 years we observed a mean SE of +0.29 D ± 0.69 D whereas at the age of 16 years the mean SE was -0.56 D ± 1.53 D. The mean SE in males was -0.01 D ± 1.14 D and in females -0.06 D ± 1.13 D. However, this difference did not reach significance (p = 0.38).

Anisometropia

Anisometropia was present in 3.7 % (n = 71) of the subjects (mean difference in SE between right and left eye: 1.73 D ± 1.13 D, range 1.0 D to 7.38 D). The prevalence of anisometropia did not differ significantly between boys and girls (χ^2 = 1.73, p = 1.0) or between children from different social strata (χ^2 = 2.24, p = 0.33). However, logistic regression showed a significant positive association with increasing age (OR = 1.13, p < 0.0001), i.e., anisometropia was more frequent in older children. At the age of 3 years, 2.3 % of the participants had an anisometropia compared to 8.1 % at the age of

16 years. Of the subjects with anisometropia, 37 % had an anisometropia of less than 1.25 D difference. For the degree of anisometropia we observed no age (p = 0.82) and no sex dependency (p = 0.23). In children with anisometropia, there was no significant difference in the mean of the SE of right and left eyes (p = 0.62), that means neither side was significantly more myopic or hyperopic.

Astigmatism

Astigmatic refractive error was prevalent in 11.8 % (n = 229) of the subjects (mean cyl: -1.34 D ± 0.80 D, range -0.75 D to -4.90 D; see also **Table 1**). Nearly half of the children and adolescents (48.5 %) with astigmatism had a slight cylinder between -1.0 D and -0.75 D, however, 8.7 % had a cylinder more than -2.5 D.

Discussion

Myopia

The prevalence rate of myopia in this study based on non-cycloplegic measurements was shown to increase with growing age from 4.0 % at age 3 to 27.0 % at age 16 (average = 10.8 %). For precise assessment of the refractive status, it is usually recommended to apply cycloplegia, since non-cycloplegic measurements tend to yield more myopic values for the sphere in the young population.[19] For ethical reasons, application of cycloplegic agents was not approved in such a large cohort. We are aware that the actual prevalence of myopia is considerably lower than our estimates as a recent published study determined significant differences for the agreement of non-cycloplegic and cycloplegic measurements of wavefront-based autorefraction (same device as in the present study) in German children aged 2 to 15 years.[24] The average difference for the SE resulted in a bias of 0.55 D (p < 0.001). Applying this correction to our data yields a corrected estimated prevalence rate of myopia of 6.4 %. Sankaridurg et al.[25] developed a method ("Model B") to determine myopic refractive errors based on a non-cycloplegic measurement of sphere and cylinder, age and uncorrected visual acuity. Likewise the authors analysed an average difference for the SE of 0.63 D in children aged 4 to 15 years living in China. Applying Sankaridurgs et al. model to our data yields a corrected estimated prevalence rate of myopia of 7.1 %. This prevalence rate might still be biased, since the authors conclude that the model might not be appropriate for non-Asian countries and very young populations where hyperopia may be the predominant refractive error. Thus, while the precise prevalence of myopia in German children and adolescents cannot be derived from the current study, the empirical measurements in combination with results from other studies comparing cycloplegic and non-cycloplegic measurements strongly suggest that the true prevalence lies below the reported 10.8 %. This is an important result, especially considering recent trends in China and East Asian countries, showing considerably higher prevalence rates of myopia. Using non-cycloplegic measurements, children at the age of 14 years living in Beijing[26] showed myopia prevalences (at least -1.0 D) of 62 %. Using the same cut-off, same-aged participants in the current study showed a prevalence rate of 17 %. This difference might be explained by a complex interaction between increasing educational pressures and increased near work activities and decreased time spent outdoors in China and East Asian countries.[27] Analyzing the influence of these and other factors in the LIFE Child cohort is beyond the scope of this paper.

The measurement-based prevalence of 10.8 % reported for German children is comparable with previous self- or parent-reported information about refractive errors in German children and adolescents.[15,16] It is also in line with those found in other European studies.[11,13] An international quantitative meta-analysis of myopia prevalences in Caucasian European ancestry residing in Europe, America, Australia and New Zealand showed prevalence rates of 1.6 % for 5-year-old, 6.7 % for 10-year-olds, 16.7 % for 15-year-olds and 22.8 % for 18-year-olds children.[28] Children and adolescents aged 7 to 16 years living in Bosnia and Herzegovina[29] as well as Swedish children aged 12 to 13 years[12] showed higher prevalence rates (20.4 % and 49.7 %).

In the current study, no gender differences were observed regarding the prevalence of myopia. This finding is supported by earlier published studies either in Europe[12] or East Asian studies.[30] In contradiction, some European and Asian studies observed a higher prevalence of myopia in females than in males.[16,26] These gender differences might be explained by more near work and less outdoor activities in females vs. males.[31]

Furthermore, similar to other European and Asian studies,[11,16,30] we observed that with older age not only the prevalence of myopia increases but also the average refractive error becomes more myopic. Parts of this change of refraction reflects the process of emmetropization, which is largely completed by the age of 6 years.[32] However, the situation in China and East Asian countries differs from that in our study. At the age of 16 years, 27.0 % of our participants had myopia and as already mentioned, this frequency is often exceeded in China and East Asian countries where also the prevalence of high myopia is higher. Lam et al.[30] reported that 1.8 % Hong Kong Chinese schoolchildren aged 6 to 12 years had high myopia of more than -6.0 D. In the study by You et al.[26] 4.3 % of Chinese children at the age of 7 to 18 years were high myopic. Consequently, the risk of pathological eye changes increases in these countries.[5] In the current study, the number of children and adolescents with high myopia is comparatively low (0.06 %, n = 12 for SE ≤ -5.0 D and 0.02 %, n = 3 for SE ≤ 6.0 D, see also **Fig. 1** and **Fig. 2**).

Hyperopia

In our study, hyperopia was found in 9.4 % of the studied population. Earlier, a prevalence rate of 5.8 % was reported for children and adolescents in Germany, based on parent-

reported questionnaires.[16] Due to accommodation hyperopic children often do not experience a reduction of visual quality and therefore might not consult the ophthalmologist. For this reason, hyperopic refractive errors often remain undiagnosed. Therefore, analyzing data only on children wearing spectacles is a significant limitation of studies like Jobke and colleagues.[16] The current results are similar to findings of hyperopia prevalence rates of 7.7 % and 9.1 % in the Netherlands[33] and Sweden.[34] Higher prevalence rates were observed in Australian children aged 4 to 12 years (38.4 %).[35] Furthermore, our results demonstrate a lower prevalence of hyperopia in older children, which is in line with the process of emmetropization. A gender difference was not observed. These findings are also supported by other European studies.[16,36]

Anisometropia

In the current study, 3.7 % of all children and adolescents had an anisometropia (≥ 1.0 D). This finding is comparable with findings on Swedish[34] (2.8 %) and Dutch children[33] (4.6 %). However, Junghans et al.[37] found an anisometropia prevalence of only 1.4 % in Australian children.

Astigmatism

The astigmatism prevalence of 11.8 % observed in the present study was lower than previously found in Chinese schoolchildren aged 4 to 16 years (36 %).[10] However, higher lid tension in Asian people is suggested to be associated with a higher prevalence of astigmatism.[38] Australian schoolchildren showed similar prevalence rates of 8.3 % for children aged 5 to 10 years and 10.5 % in 11- to 20-year-old children,[39] compared to our study.

Strengths & limitations

The present paper presents, for the first time in Germany, measurement-based data describing the refractive status in children and adolescents. Other strengths were the large age range with a high participation rate of children in all age-groups. The limitation of our study was that cycloplegia was not performed due to ethical and organizational reasons. As stated previously, accommodation might affect the refractive error leading to an overestimation of myopia or an underestimation of hyperopia. In addition, hyperopia might be undetected. Finally, the generalizability of study findings to the whole population of German children might be limited due to a slight underrepresentation of children from lower social strata and from rural areas in the LIFE Child study sample.

Conclusions

The prevalence of myopia in German children and adolescents increases with child age. The overall myopia prevalence in children in Germany aged 3 to 16 years is around or even less than 10 %, taking into consideration that measurements were carried out without cycloplegic agents. Our results are comparable to other European paediatric studies. Even though the mean prevalence of myopia is (still) lower than in other, East Asian countries, it is a health concern that should be taken seriously, for example because of the risk of myopia-related secondary diseases in adulthood. The risk for these diseases, such as myopic maculopathy and retinal detachment, increases with increasing level of myopia. Measures to reduce myopia (e.g. by limiting near-work activity and promoting outdoor activity) should start in early childhood and be followed up consistently.

Conflict of interest

S. Wahl is an employee of Carl Zeiss Vision International GmbH. The author has no financial or conflicting interests concerning the content of this research which was conducted following the rules of neutral scientific practice.

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