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Impaired visual acuity caused by uncorrected refractive errors and amblyopia in a German paediatric cohort

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Abstract

Purpose: This study describes the prevalence of visual impairment caused by uncorrected distance refractive error and the spectacle coverage in a large cohort of German children and adolescents. Furthermore, we determined the prevalence of amblyopia and amblyopia treatment.

Methods: Optometrists carried out visual acuity (VA) testing, non-cycloplegic autorefraction, VA retesting with the refractive correction obtained by autorefraction, and if necessary subjective refraction and cover-test in 1,874 subjects (901 girls/973 boys), aged 3 to 16 years. Additionally, a questionnaire on the history of previous eye care was completed.

Results: Distance visual impairment (VI) with VA worse than 6/18 Snellen in the better eye was present in 0.5% (95% confidence interval [95% CI]: 0.2% to 0.9%) of children. Logistic regression showed a significant positive association between VI and older age (OR = 1.21, $P = 0.03$). Gender differences were not found ($P = 0.77$). The spectacle coverage of all participants was 74.8% (95% CI: 65.2% to 82.8%). Amblyopia was found in 29 participants (1.5%; 95% CI: 1.0% to 2.2%) with no age or sex differences. The causes of unilateral amblyopia (27 cases, 93.1%) were anisometropia in 55.6% of children, strabismus in 25.9% and the combination of these factors in 18.5%. All children with bilateral amblyopia (2 cases, 6.9%) showed bilateral high ametropia. We observed 15 children with current amblyopia, who had been treated with occlusion therapy in the past (62.2%; 95% CI: 42.7% to 83.6%).

Conclusions: The prevalence of impaired VA caused by uncorrected refractive error and amblyopia is comparable with previous studies conducted in urban areas worldwide. Adding the measurement of refractive error to existing medical check-ups, possibly using autorefraction, would be desirable.

Introduction

Distance refractive error affects a large proportion of the global population. If current trends continue, then half of the world's population will be myopic in 2050.[1] This prediction has major implications for children and adolescents today. Although refractive errors can easily be corrected with spectacles, uncorrected distance refractive error is the most common cause of moderate or severe distance visual impairment (VI).[2] VI can restrict social development and education and has economic impacts on society.[3,4] Worldwide, 12.8 million children aged 5 to 15 years are visually impaired due to uncorrected or inadequately corrected refractive errors.[5]

In addition, amblyopia is a frequent cause of decreased visual acuity (VA).[6–8] It represents a unilateral visual

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developmental disorder in the absence of organic disease. Common causes of amblyopia are anisometropia and strabismus or a combination of the two. In strabismus, the child's brain suppresses the image of the deviated eye to prevent diplopia, and VA cannot develop fully. Other causes such as bilateral high ametropia, congenital cataract and corneal opacity are rare and lead eventually to bilateral amblyopia. The prevalence rates of amblyopia in children vary from 1.2% in Singapore[9] to 2.6% in Hispanic children in the USA.[10] European data show prevalence rates between 1.5% and 3.1%.[11–13] There is limited information regarding the prevalence of amblyopia in German children and adolescents.

To date, few studies on the progression of untreated amblyopia have been published. They have shown either no or minimal improvement over time.[14,15] Treatment for amblyopia consists of prescribing spectacles to correct refractive errors, occlusion therapy or pharmaceutical penalisation of the healthy eye. The latter therapy is relatively uncommon in Germany. Unsuccessful treatment of amblyopia during the sensitive period of visual development leads to reduced VA and abnormal binocular vision in adulthood. Subsequently, spectacles or contact lenses can only produce limited improvement in vision. Thus, refractive error, VA and spectacles should be monitored regularly in childhood.[16]

In Germany, regular vision screenings at paediatric practices are performed. Between the third and tenth day of life and again between six and seven months of age a Bruckner-Test is usually performed. VA and stereopsis are checked at 3 and 5 years of age by paediatricians.[17]

Early detection of reduced VA is an important issue. Therefore, there is a need to estimate the prevalence of uncorrected refractive error and amblyopia to understand the need for screening, detection and intervention within the German health system. For these reasons, the present study aimed to determine the prevalence of VI caused by uncorrected distance refractive error, and the prevalence of spectacle coverage in a large cohort of German children and adolescents. The prevalence of both amblyopia and amblyopia treatment was also assessed.

Methods

Study sample

Data were collected from January 2014 to May 2018 at the LIFE Child study centre in Leipzig, Germany. The LIFE Child study (clinical trial number NCT02550236) is a longitudinal childhood cohort study aimed at investigating healthy child development and the development of diseases such as diabetes, asthma and obesity.[18,19] Most participants came from the city of Leipzig and surrounding areas. They were recruited via advertisement at various institutions, e.g., schools and public health centres. All families interested in the study were invited to participate. Children suffering from any severe chronic, chromosomal or syndromal diseases were excluded. Follow-up visits were scheduled every year. As in many cohort studies, there was a tendency towards a higher socio-economic status in the LIFE Child study, with 14%, 57% and 29% of families having low, middle and high socio-economic status, respectively.[20] The LIFE Child study was independent of the regular health check-ups performed by paediatricians in Germany. If the children attended these routine examinations, then a Bruckner-Test and VA measurement was carried out at 3 and 5 years of age by the paediatrician, and if reduced VA was found, then they were referred to an ophthalmologist.

Informed written consent was provided by all parents before the inclusion of their children in the study, which 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). Baseline measurements were recorded from 1,934 children and adolescents between 3 and 16 years of age (925 girls, 1,009 boys, mean age = 9.1 years; S.D. = 3.9 years).

Examination procedures

All participants underwent a comprehensive eye examination, conducted by a team of three optometrists who were trained in the standardised study protocol. Noncycloplegic refractive error of each eye (3 mm pupil diameter and 12 mm vertex distance) was measured three times using an autorefractometer (ZEISS i.Profiler® Plus, www.zeiss.de). The repeatability of the three measurements was ±0.78 D.[21] Monocular VA was determined (both uncorrected and with the habitual correction if worn) at 6 m with ambient room lighting using a retro-illuminated logMAR chart (ZEISS i.Polatest®, www.zeiss.de) with single line presentation and a 0.1 log unit difference between the lines. For children who were unable to read letters, line or single Kolt-test optotypes were presented.[22] A line was passed if three out of five optotypes were read correctly. If VA was worse than 20/40 Snellen, then the refractive correction obtained from the autorefractometer was placed in a trial frame and VA re-measured through this correction. If VA remained below 20/40, a subjective refraction was carried out to determine the best corrected VA (BCVA). A cover-test with fixation at 0.4 m was used to check for heterotropia. A questionnaire asking about previous visits to ophthalmologists or a history of eye surgery, eye disease, occlusion therapy or the use of spectacles was completed by the parents (for children under 10 years of age) or by the children themselves (Appendix 1). OCT and biometry measurements were also performed, but the results of these tests were not included in this analysis.

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Definition of visual impairment and spectacle coverage

Presenting distance VI caused by uncorrected or inadequately corrected refractive errors was defined as worse than 6/18 in the better eye. This definition is in line with the following WHO categories: moderate VI defined as uncorrected or presenting VA (spectacle-corrected VA, if worn) worse than 6/18 to 6/60 inclusive; severe VI defined as uncorrected or presenting VA worse than 6/60 to 3/60 inclusive, and blindness defined as uncorrected or presenting VA worse than 3/60.[23]

Spectacle coverage was defined as the percentage of "met need" divided by "total need" (the combination of met and unmet need) according to Bourne et al.[24]:

$$\text{Spectacle coverage}(\%) = \frac{met\ need}{total\ need} * 100\%$$

Participants who wore spectacles and had distance VA worse than 6/12 in the better eye without correction but achieved 6/12 or better in the better eye with their own spectacles were designated as "met need" for spectacles.

"Unmet need" was defined as the number of subjects who had VA worse than 6/12 in the better eye without correction and could achieve 6/12 or better in the better eye with correction, but either did not wear spectacles or did not achieve this level of VA with their present spectacles. Participants who did not bring their spectacles and had VA worse than 6/12 in the better eye without correction but could achieve 6/12 or better in the better eye with correction were also defined as "unmet need".

Definition of amblyopia

Amblyopia was defined as reduced VA in the presence of a known risk factor without any obvious structural or pathological anomalies. Similar to the definition in MEPEDS,[25] unilateral amblyopia was defined as a two-line interocular difference, with BCVA of ≤20/32 Snellen in the worse eye and having at least one of the following risk factors in the affected eye: strabismus, previous strabismus surgery, anisometropia consistent with the worse eye (difference of ≥3.00 D of myopia, ≥1.00 D of hyperopia or ≥1.50 D of astigmatism) or evidence of past or present visual axis obstruction (e.g., congenital cataract, intraocular lens, aphakia, corneal opacity, ptosis or eyelid haemangioma). Bilateral amblyopia was defined as a condition of bilateral subnormal BCVA < 20/40 and presenting amblyogenic factors including bilateral high ametropia (myopia ≥ 6.00 D, hyperopia ≥ 4.00 D or astigmatism ≥ 2.50 D) and evidence of past or present visual axis obstruction. Children with a two-line interocular difference and a VA of <20/40 in the better eye were classified as unilaterally amblyopic, according to the MEPEDS criteria.

Data analysis

Participants between 3 and 16 years of age with complete VA data were included in the statistical analysis. All analyses were conducted using R, version 3.3.4 (GNU Operating System, www.gnu.org). Prevalence rates and their corresponding 95% confidence intervals of VI, spectacle coverage, amblyopia and treatment of amblyopia (spectacle wear and occlusion therapy) were determined. Gender differences and differences in the prevalence rates of the right and left eyes which were affected by unilateral amblyopia, were tested by χ^2 tests. Logistic regression was used to examine odds ratios (OR) to assess associations between the prevalence of VI and amblyopia with age. The alpha significance level was set to 0.05.

Results

Study population

Of the 1,934 participants between 3 and 16 years of age, complete VA measurements could not be performed in 60 children because of limited cooperation. Therefore, these children were excluded from the analysis. The final analysed sample consisted of 1,874 children and adolescents (901 girls, 973 boys, mean age = 9.2 years, S.D. = 3.9).

Prevalence of visual impairment and spectacle coverage

A total of 284 (15.2%) children and adolescents (149 girls, 135 boys; $P = 0.12$) reported wearing spectacles. Of these participants, 33 (11.6%) did not bring their spectacles to the examination and therefore were classified as non-wearers. Presenting VA was determined in 251 children and adolescents (13.4% of all children in the study cohort) with their habitual correction.

VI (VA worse than 6/18) as a result of uncorrected or inadequately corrected refractive error was found in 10 participants (0.5%; 95% confidence interval [95% CI]: 0.3% to 1.0%). The data showed a significant association between a higher prevalence of VI and older age (OR = 1.21 per +1 of year of age, $P = 0.03$). Boys ($n = 6$) were more frequently affected than girls ($n = 4$). However, this difference did not reach statistical significance ($\chi^2 = 0.09$, $P = 0.77$). Moderate VI was observed in nine participants (0.5%; 95% CI: 0.2% to 0.9%) and severe VI found in one child (0.1%; 95% CI: 0.0% to 0.3%). No subject was blind (*Table 1*).

The spectacle coverage of all participants who required glasses to improve their vision was 74.8% (95% CI: 65.2% to 82.8%). A need for spectacles was identified in 103 children and adolescents (50 girls; 53 boys; $P = 0.80$). Of these

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Table 1. Prevalence of visual impairment (VI) due to uncorrected refractive error by age, gender and types of VI

Characteristics	Without VI (n)	With VI (n)	Prevalence of VI (%; 95 CI)
Total	1864	10	0.5; 0.3 to 1.0
Age (year)			
3 to 4	347	1	0.3; 0.0 to 0.02
5 to 6	335	0	0
7 to 8	248	0	0
9 to 10	274	0	0
11 to 12	301	6	2.0; 0.7 to 4.2
13 to 14	190	2	1.0; 0.1 to 3.7
15 to 16	169	1	0.6; 0.01 to 3.2
Sex			
Female	897	4	0.4; 0.1 to 1.1
Male	967	6	0.6; 0.2 to 1.3
Type			
Moderate VI	N/A	9	0.5; 0.2 to 0.9
Severe VI	N/A	1	0.1; 0.0 to 0.3
Blindness	N/A	0	0

The total number of children analysed was 1,874. N/A, not applicable.

Table 2. Prevalence of amblyopia stratified by age, gender and types of amblyopia

Characteristics	Without amblyopia (*n*)	With amblyopia (*n*)	Prevalence of amblyopia (%; 95 CI)
Total	1843	29	1.5; 1.0 to 2.2
Age (year)			
3 to 4	343	4	1.2; 0.3 to 2.9
5 to 6	330	5	1.5; 0.5 to 3.4
7 to 8	241	7	2.8; 1.1 to 5.7
9 to 10	269	5	1.9; 0.6 to 4.2
11 to 12	303	3	1.0; 0.2 to 2.8
13 to 14	189	3	1.6; 0.3 to 4.5
15 to 16	168	2	1.2; 0.14 to 4.2
Gender			
Female	891	9	1.0; 0.5 to 1.9
Male	952	20	2.1; 1.3 to 3.2
Type			
Unilateral	N/A	27	1.4; 1.0 to 2.1
Anisometropic	N/A	15	0.8; 0.4 to 1.3
Strabismic	N/A	7	0.4; 0.1 to 0.7
Combined*	N/A	5	0.3; 0.09 to 0.62
Deprivational	N/A	0	0
Bilateral	N/A	2	0.1; 0.01 to 0.38
Refractive	N/A	2	0.1; 0.01 to 0.38

*Strabismic and anisometropic. N/A, not applicable

participants, 77 (42 girls, 35 boys; $P = 0.77$) wore appropriate spectacles (met need) and 26 (8 girls, 18 boys; $P = 0.06$) wore either no or undercorrected spectacles (unmet need). One child wore inadequately corrected spectacles (unmet need) and showed uncorrected VA of 6/12 in each eye. Setting the cut-off between met and unmet need at 6/18 yielded a spectacle coverage of 83.1%.

Prevalence of amblyopia and amblyopia treatment

Using the MEPEDS criteria, decreased VA that could not be improved with optical correction was found in 29 children and adolescents. Accordingly, amblyopia was found in 1.5% (95% CI: 1.0% to 2.2%) of the analysed sample. The prevalence of amblyopia was more than twice as high in boys ($n = 20$) than girls ($n = 9$), although the χ^2 test showed no significant difference ($\chi^2 = 2.77$, $P = 0.10$), probably due to the low number of cases. Furthermore, we observed no association with age (OR = 1.00, $P = 0.95$). Unilateral amblyopia was diagnosed in 27 cases (93.1% of all children with decreased VA). In 16 of these participants, amblyopia was present in the right eye, compared to 11 in the left eye ($\chi^2 = 0.93$; $P = 0.34$). Anisometropia was present in 15 cases (55.6%), strabismus (including 6 esotropia and 1 exotropia) in 7 cases (25.9%) and a combination of the two in 5 cases (18.5%, all including esotropia). Bilateral amblyopia was diagnosed in two cases (6.9%) due to bilateral high ametropia (*Table 2*).

As no clear definition of amblyopia exists, we applied different definitions and age ranges from previous studies to our data in order to make the results comparable. *Table 3* shows the prevalences identified in other European studies for participants in childhood and adolescence in comparison to our data when applying the respective criteria. Additionally, the prevalence rate of amblyopia in a German adult population[26] aged 35–74 years is included, in order to determine whether there is an improvement in eye health care for children at the present time.

Based on self- or parent-reported information, 6 of the 29 amblyopic children and adolescents (20.7%; 95% CI: 8.0% to 40.0%) aged 4 ($n = 3$), 7, 10 and 12 years had never noticed reduced VA, nor was this noted by their parents. For these reasons, an ophthalmologist was not consulted. Of the remaining participants, 20 children and adolescents wore spectacles (69.0%, 95% CI: 49.2% to 84.7%) and 15 had already received a diagnosis of amblyopia and were treated previously with occlusion therapy (51.7%, 95% CI: 32.5% to 70.6%). The provision of spectacles and occlusion therapy was carried out in 12 participants (41.4%, 95% CI: 23.5% to 61.1%). Those participants who had been to an ophthalmologist but were not corrected with spectacles ($n = 3$), 2 (aged 9 and 14 years) had little refractive error and their amblyopia was due to strabismus. Another 14-year old child had anisometropic astigmatism of 4 D and decided to stop wearing spectacles at 13 years of age. All of these three participants had been treated with occlusion therapy in the past. Furthermore, using the information from the questionnaires, we assessed that 34 participants who suffered from amblyopia in the past had been treated successfully with

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Table 3. Amblyopia prevalence rates in prior European studies and adjusted prevalence rates (using the same definition and age range) in the current study

Authors	Country	Age [years]	Amblyopia definition	Prevalence	Prevalence in this study
Ohlsson et al. (2001)	Sweden	12–13	BCVA < 6/12 and ≥ 2 lines differences	1.1 %	1.1 %
Grounewoud et al. (2010)	Netherlands	7	Unilateral: ≥ 2 line differences; Bilateral: BCVA < 6/9.5	3.4 %	4.0 %
Sandfeld et al. (2018)	Denmark	4.5–7	≥ 2 lines differences and/or BCVA < 6/12	2.7 %	2.2 %
Hansen et al. (2018)	Denmark	11–12	Unilateral: BCVA < 6/7.5 and ≥ 2 lines differences; Bilateral: BCVA < 6/7.5	1.5 %	1.0 %
Elflein et al. (2015)	Germany	35–74	Unilateral: BCVA ≤ 6/9.5 and ≥ 2 lines differences or ≤ 6/12 without such a difference; Bilateral: BCVA < 6/9.5	5.6 %	N/A

N/A, not applicable.

occlusion therapy based on the MEPEDS criteria to date. Thus, more than half of the children who had previously been diagnosed with amblyopia no longer had the condition (54.0%; 95% CI: 41.0% to 66.6%).

Discussion

Prevalence of visual impairment and spectacle coverage

This study provided novel findings on the prevalence of impaired VA caused by uncorrected or inadequately corrected refractive errors in a large paediatric cohort in Germany. None of the analysed 1,874 participants was blind, although 0.5% were VI. This prevalence rate is lower than the estimated prevalence of VI worldwide (0.97%) from Resnikoff *et al*.[5] These authors reviewed a series of published and unpublished surveys of the prevalence of VI (VA less than 6/18 in the better eye) attributed to uncorrected refractive errors in children 5 to 15 years of age in several World Health Organisation (WHO) countries. Findings from the WHO Eastern Mediterranean Region (Iran, Lebanon, Oman and Qatar) and the WHO South-East Asia Region (Bangladesh, Nepal and Pakistan) are comparable with the prevalence found here (0.6%). The WHO African Regions, i.e., Mali, Mauritania and South Africa showed lower prevalence (0.2%), which may be due to low rates of both myopia and clinically significant hyperopia (≥ +2 D) in these areas.[27,28] Higher prevalence rates of VI were reported in the USA (1.0%) and urban areas of China (2.7%). Studies from these regions reported significantly higher prevalence rates of myopia and astigmatism[29–31] compared to Germany,[32] which may explain the higher VI rates.

Similar to other studies,[6,7,33] we discovered higher rates of VI in older children. This association is in accordance with an increasing prevalence of myopia with age in our cohort.[32] Moreover, a nationwide, population-based survey (KiGGS) presented a significant increase in spectacle wearing with increasing age in Germany.[34] A sex dependency was not observed, which is in line with previously work.[7,35]

In the current investigation, uncorrected distance VA worse than 6/12 in the better eye was present in 5.5% of the studied population. Of these participants, 74.8% wore appropriate spectacles with which they achieved VA of 6/12 or better. 25.2% wore either no or inadequate spectacles. The reasons for this undersupply was not determined. Possible reasons may have been that the prescriptions were incorrect, or that knowledge or accessibility was insufficient. Investigations of Chinese children pointed out that some parents, who were aware of their child´s poor vision, did not want their child to wear eyeglasses. Other parents stated that spectacles were too expensive, and some did not know how to obtain eyeglasses.[36] Perhaps parents in the current study were unaware of their child´s visual difficulties, as unfortunately poor vision is often not easy to discover in children, especially if strabismus is not present. In addition, some ametropia may go unnoticed, especially if it is only present in one eye.

Medical check-ups, including vision screening (determination of VA and strabismus) are available in the German health system up to 5 years of age. However, these examinations are performed by paediatricians, rather than ophthalmologists or optometrists. The interval of medical paediatric check-ups should be reconsidered and, if possible, extended to regular vision screenings after 5 years of age, especially since the KiGGS study recently showed that spectacles were most frequently prescribed for the first time at the age of 10 years.[34]

In contrast to Germany, only 30 - 40% of children aged 5 to 15 years living in an urban area of India and in a suburban area of Malaysia were equipped with adequate spectacles.[37,38] Using a cut-off of VA < 6/18, spectacle coverage in the current study was 83.1%, which was similar to findings in urban areas of the WHO Eastern Mediterranean Region and urban areas of China (80% to 85%).[5] Urban areas in South America, South-East Asia and India presented coverages around 50%.[5]

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Prevalence of amblyopia and amblyopia treatment

This study filled the gap of knowledge on the prevalence of amblyopia and amblyopia treatment in German children and adolescents. Amblyopia was found in 1.5% of the analysed sample. Refractive errors were major amblyogenic factors. In unilateral amblyopia (27 participants), anisometropia was present in 55.6% of children, strabismus in 25.9% and a combination of these factors in 18.5%. All children with bilateral amblyopia showed bilateral high ametropia. These distributions are consistent with earlier published studies.[39,40] Comparing amblyopia prevalence rates is difficult due to incongruous age groups, varied measurement methods for determining VA and variability in the definition of amblyopia. Therefore, overall prevalence rates vary across the world. A lower amblyopia prevalence rate (0.7%) was observed in Chinese children aged 4–18 years using the same cut-off criteria as the present study.[29] Children aged 6—14 years living in Turkey presented higher prevalence rates (2.6%).[41] Using the cut-off criteria and restricting age to the same range as that of Caca et al.[40] yielded a prevalence of 1.9% for our cohort. The distribution of amblyopia in the children and adolescents observed here is similar to that of previous European studies (*Table 3*).[11,42–44]

Comparing these findings with those from a prior German survey in participants aged 35–74 years shows that the prevalence of amblyopia in the current study was much lower (1.5% vs. 5.6%).[26] This suggests that eye care has improved from previous years so that now more children with amblyopia are identified and treated.

Spectacles were prescribed in 69% of children who presented with amblyopia and 51% were treated with occlusion therapy. Both treatments were indicated in 41% of children with amblyopia. The reasons for failed treatment were not investigated here. They may have been due to lack of compliance or treatment being introduced too late. Some children had received occlusion therapy which was already completed, while in other children the therapy was still ongoing.

The present study indicated that six children with amblyopia (20.7%) were not discovered by medical check-ups, suggesting that the efficacy of screening for amblyopia in Germany can be improved. Examination guidelines require VA tests with single optotypes at a 3 m distance (e.g., Lea symbols and Sheridan Gardiner Test) to detect amblyopia. VA tests are often challenging to perform at preschool ages. While the examiners had sufficient time to perform the investigations in the present study, even here about 3% of the children did not complete the VA measurements. Furthermore, lines of optotypes should also be included as closely spaced optotypes can be difficult for children with amblyopia to distinguish. Since refractive error was the major amblyogenic factor in the current study, screening methods such as auto- and photo-refraction would be helpful in future medical check-ups. While early detection can be achieved by ophthalmologists and optometrists, not all children can be provided for due to the lack of eye care practitioners in Germany.

Strengths & limitations

The present paper is the first to present data from Germany describing impaired VA due to uncorrected refractive errors and amblyopia in children and adolescents. A strength is the broad age range and high participation rate. A limitation of this study was that measurement of VA was carried out with results obtained by autorefraction, if VA was less than 20/40 with their habitual correction. However, if VA was still below 20/40 with the autorefractor findings, then a subjective refraction was performed to avoid overestimation of VI. Furthermore complete VA measurement could not be performed in some participants up to the age of 4, as they were too young to cooperate sufficiently. Therefore, data from these children were not analysed. Finally, the generalisability of study findings to the whole population of German children might be limited due to a slight underrepresentation from lower social strata and rural areas in the LIFE Child study sample.

Conclusions

As visual requirements become more sophisticated in high-skilled jobs, good vision is more important than ever in today´s world to ensure a robust economic future. In our paediatric cohort, we observed a prevalence of VI caused by uncorrected refractive error of 0.5% and a prevalence of amblyopia of 1.5%. Both vision problems require treatment. Therefore, preventive eye-care services, which are already established by medical check-ups in Germany, need to be performed regularly in childhood. However, because uncorrected refractive error is the most common cause of impaired VA, it would be preferable to introduce eye-care examinations using modern auto- or photo-refraction. Additionally, regular check-ups should take place after the fifth year of life, as our results show that VI was more prevalent in older children. Furthermore, there is a need to educate parents and teachers further to the prevalence of vision problems in children.

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Conflict of interest

S. Wahl is a scientist at the University Tübingen and an employee of Carl Zeiss Vision International GmbH, and was involved in the writing, analysis and control over publication. S. Wahl reports no conflicts of interest and has no proprietary interest in any of the materials mentioned in this article.

Author contribution

Manuela Brandt: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Investigation (lead); Methodology (lead); Project administration (lead); Writing-original draft (lead). **Carolin Truckenbrod:** Data curation (supporting); Writing-original draft (supporting); Writing-review & editing (equal). **Christof Meigen:** Software (equal); Supervision (equal); Validation (equal); Writing-review & editing (supporting). **Mandy Vogel:** Writing-review & editing (supporting). **Tanja Poulain:** Writing-review & editing (supporting). **Wieland Kiess:** Funding acquisition (equal); Project administration (equal); Resources (equal). **Siegfried Wahl:** Supervision (equal); Writing-review & editing (equal).

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Appendix 1

Eye health interview in the LIFE Child Study

1. Who is answering the questions?
   - Mother
   - Father
   - Child him/herself
   - Stepmother/partner of the father
   - Stepfather/partner of the mother
   - Adoptive mother
   - Adoptive father
   - Grandmother
   - Grandfather
   - Caregiver
   - Other
2. Did you already take part in an eye examination at LIFE Child?
   - Yes
   - No

Eye health of the child

In the first part, we would like to know some things about the eye health of the child that does take take part in the examination

3 Has you child ever been to the eye doctor?
   - Yes
   - No (skip until Question 18)
   - Don't know (skip Question 18)

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4 How old was your child, when it was to the eye doctor for the first time (if you don't know, leave the answer blank)
- My child was. . . months old
- My child was. . . years old

5 Why were you with your child to the eye doctor (severals answers are possible)?
- The child had bad vision
- The child had a learning disability (for example dyslexia)
- The child was cross-eyed
- The child had a eye injury/foreign object in the eye
- Routine examination
- Pain in the eye, feeling of strain
- Anomaly detected in the routine preventive care examinations
- Anomaly detected in a LIFE Child visit
- Other

6 Did your child have eye surgery?
- yes (please describe waht kind of eye operation)
- no
- I don't know

7 Did your child ever have to wear an eye path/occlusion foil or something similar?
- Yes, on the right eye
- Yes, on the left eye
- Yes, on both eyes
- No
- I don't know

8 Does or did your child ever wear glasses?
- Yes, currently
- Yes, but not currently
- No

9 Does or did your child ever wear contact lenses?
- Yes, currently
- Yes, but not currently
- No

10 At what age did your child get its first glasses?

11 Please answer the questions about wearing glasses/contact lenses (options yes, no, no answer):
- My child wears glasses/contact lenses the whole day
- If the child does not wear glasses/contact lenses the whole day, does it wear them for certain activities like sports or during school?
- Should your child wear glasses/contact lenses, but doesn't do it most of the time (or ever)?

12 Did your child stop wearing contact lenses because he/shoe does not need them anymore?
- Yes
- No (skip the next two questions)
- No answer (skip the next two questions)

13 At what age did your child stop wearing glasses/contact lenses?

14 Who decided that the child should stop wearing glasses/contact lenses?
- Optician
- Orthoptist
- Parents
- Child

15 How often were the glasses/contact lenses values checked?
- About twice a year or more often
- About annually
- Every two years or less frequently
- I don't know

16 Who checked the values?
- Eye doctor
- Optician
- I don't know

17 Further remarks:

Eye health of siblings

Now we would like to ask some questions about (half)siblings

18 Does your child have siblings or half-siblings?
- Yes
- No (skip further questions in this section)
- Don't know (skip further questions in this section)

19 What kind of (half)siblings does your child have?
- Siblings
- Half-sibling from the mother's side
- Half-siblings from the father's side

20 Please state the number of siblings with and without glasses/contact lenses
- total number:
- number using glasses/contact lenses:
- number not using glasses/contact lenses:

21 Please state the number of half-siblings from the mother's side with and without glasses/contact lenses:
- total number:
- number using glasses/contact lenses:
- number not using glasses/contact lenses:

22 Please state the number of half-siblings from the father's side with and without glasses/contact lenses:
- total number:
- number using glasses/contact lenses:
- number not using glasses/contact lenses:

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Leisure activities of your child

Now we would like to know something about how your child spends leisure time.

23 (For the interviewer): At which season was the interview conducted:
- Spring
- Summer
- Autum
- Winter

24 Does your child read, write or paint during leisure time?
- Yes
- No (Skip the next 4 questions)
- Don't know (Skip the next 4 questions)

25 What of these leisure activities does your child do up close (multiple answers possible)?
- Reading
- Writing
- Painting

26 How often does your child do these activities?
- Every day
- Every other day
- Twice a week
- Once a week

27 For how long does your child do these activities?
- Less than 1 h
- 1–2 h
- 3–4 h
- more than 4 h

28 At what distance does your child usually do these activities?
- 0–10 cm
- 10–20 cm
- 20–30 cm
- 30–40 cm
- More than 40 cm
- I don't know

29 Does your child use screen devices (smartphone, game consoles, laptop)?
- Yes
- No (skip the next four questions)
- I don't know (skip the next four questions)

30 What screen devices does your child use?
- Smartphone
- PC
- Laptop
- Video games on TV screen
- Video games on handheld devices
- Kindle etc

31 How often does your child use screen devices?
- Every day
- Every other day
- Twice a week
- Once a week

32 For how long does your child use screen devices?
- Less than 1 h
- 1–2 h
- 3–4 h
- More than 4 h

33 At what distance does your child usually use screen devices?
- 0–10 cm
- 10–20 cm
- 20–30 cm
- 30–40 cm
- 50–60 cm
- 60–100 cm
- More than 100 cm

34 Does your child watch TV?
- Yes
- No (skip the next 3 questions)
- I don't know (skip the next 3 questions)

35 How often does your child watch TV per week?
- Every day
- Every other day
- Twice a week
- Once a week

36 How long does your child watch TV?
- Less than 1 h
- 1–2 h
- 3–4 h
- More than 4 h

37 At what distance does your child usually watch TV?
- Less than 1m
- 1–2 m
- 2–3 m
- More than 3m
- I don't know

38 Does your your child spend time outside (playing, doing sports)?
- Yes
- No (skip the next two questions)
- Don't know (skip the next two questions)

39 How often does your child spend time outside?
- Every day
- Every other day
- Twice a week
- Once a week

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40 How long does your child spend time outside?
- Less than 1 h
- 1–2 h
- 3–4 h
- More than 4 h

41 Do you live in an rural or urban area?
- Rural
- Urban

42 Further remarks:

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