Characteristics of axial Length and Binocular axial Length Difference in Chinese Children and Teenagers

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Research Article

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Abstract

Background: To investigate the characteristics of axial length and binocular axial length difference in Chinese children and teenagers.

Methods: The axial length and binocular axial length difference of 4422 children were retrospectively reviewed in this school-based study, while duration of outdoor activities, total media exposure (including electronic devices usage and TV watching) and sleep were also analyzed.

Results: The average axial length of all ages were 23.20±0.02mm in the right eyes and 23.18±0.02mm in the left eyes. The binocular axial difference was 0.16±0.24mm. There was a slow rising trend in axial length (AL) within age. Mean AL in boys was 0.49mm longer than that in girls. Those who wore frame glasses were generally having shorter AL in preschool children (mean AL: 22.29±0.69mm vs 21.84±1.06mms) and longer AL in elder children (mean AL: 24.11±1.34mm, 25.06±1.07mm, 25.39±1.02mm vs 23.07±0.83mm, 23.84±0.95mm, 24.05±0.98mm). No significant difference was found between age in AL and ALD since age 15 and age 12. Parental myopic background was related to AL in all age groups, and total media exposure was related to longer AL in junior and senior high school students. Longer outdoor activities, longer sleep duration were associated with a shorter AL in primary school students. ALD was only associated with age in primary school students.

Conclusion

Axial length and binocular axial length difference varied within age, and they did not show an increase since the age of 15 and 12, respectively. Male, longer sleep and longer outdoor durations were associating with shorter axial length in younger children; female, longer total media exposure and parental myopic background were associating with a longer axial length especially in adolescents.

Background

Anisometropia, a phenomenon that could be the cause and effect of anomalous refractive development or abnormal visual stimuli, was variable throughout childhood and puberty. The incidence rate of anisometropia varied through different ages[1], and whether the magnitude of anisometropia correlated with myopia progression was yet to be discovered[2]. Anisometropia was generally adopted as a difference of cycloplegic refraction > 1.0D in both eyes. It could directly affect stereopsis, lead to aniseikonia[3] or amblyopia[4][5].

For young children and teens, axial length gradually grows longer with age, while asymmetrical binocular axial growth in two eyes could result in temporal or permanent axial-anisometropia. According to previous studies, anisometropia was mainly associated with hyperopia[6], strabismus[7], accommodative responsibility[8] or age[9][10]. Since anisometropia might have something to do with later-onset myopia, hyperopia or even amblyopia, the relation between anisometropia and myopia-related living habits were worthy of being investigated. Most studies were more engaged in analyzing refractive anisometropia, but
our research managed to analyze axial anisometropia by analyzing the differences of axial length between both eyes throughout childhood and puberty, and life habits as well as parental characteristics were also taken into consideration.

**Methods**

**Participants and measurements**

It was a cross-sectional school-based study, and 4422 children and teenagers aged 3 to 17 were enrolled from four kindergartens, two primary schools, two junior high schools and two senior high schools in Pujiang Downtown, Shanghai, China. All were the race of Han. The participants received ocular examinations including uncorrected visual acuity (UCVA), noncycloplegic autorefraction, keratometry, axial length (AL, from at least 3 consecutive examinations by IOL Master). Exclusion criteria included strabismus, cataract, glaucoma and previous ocular history of either eye. Parents or their legal guardians were required to fill in a questionnaire that recorded children's daily duration of TV-watching, electronic devices usage, outdoor activities and sleep as well as their own myopic state and education degree. The study was approved by Review Board of Fudan Eye and ENT hospital, and written informed consent was obtained from all participants. The study conducted was adhered to the tenets of the Declaration of Helsinki.

**Statistical analysis**

Statistical analyses were performed with SPSS 22.0. Continuous data were presented as mean ± SD, and discrete data were presented as number (%). The assumption of normal distribution of data was tested by the Shapiro-Wilk test. Differences in continuous parameters were examined with one-way ANOVA and in discrete parameters were Chi-square tests. LSD post-hoc tests were used for subgroups tests. The associations between axial length, binocular axial length difference and other parameters were performed with stepwise multivariate analysis. All $P$ values were two sided and $P<0.05$ was considered to possess statistically significance.

**Results**

**General characteristics**

A total of 4422 children and teenagers were enrolled in this study, and their general characteristics were listed in Table 1. Binocular axial length difference was described as ALD. Boys had an average 0.49 mm longer AL than girls, but no significant difference was found in ALD between gender. A high correlation was found between right eyes and left eyes in all the students ($r = 0.977$, $P<0.001$).
| Characteristics               | N (%)       | Mean ± SD or median (range) |
|------------------------------|-------------|-----------------------------|
| Gender                       |             |                             |
| Boy                          | 2233(50.5%) |                             |
| Girl                         | 2189(49.5%) |                             |
| Age (years)                  | 8.04 ± 4.25 |                             |
| Grade                        |             |                             |
| Preschool                    | 2051(46.4%) |                             |
| Primary school               | 1080(24.4%) |                             |
| Junior high school           | 792(17.9%)  |                             |
| Senior high school           | 499(11.3%)  |                             |
| UCVA (right eyes, logMAR)    | 0.10(0-0.22)|                             |
| UCVA (left eyes, logMAR)     | 0.10(0-0.22)|                             |
| AL (right eyes)              | 23.20 ± 1.38|                             |
| AL (left eyes)               | 23.18 ± 1.36|                             |
| Average AL (mm)              | 23.19 ± 1.37|                             |
| ALD (mm)                     | 0.16 ± 0.24 |                             |
| CR (mm)                      | 7.81 ± 0.26 |                             |
| AL/CR                        | 2.97 ± 0.16 |                             |
| Paternal age (years)         | 28.48 ± 0.06|                             |
| Maternal age (years)         | 26.33 ± 0.06|                             |
| Education degree of father   |             |                             |
| Junior high school and below | 844(19.1%)  |                             |
| Senior high school           | 1505(34.0%) |                             |
| College                      | 1088(24.6%) |                             |
| University and above         | 974(22.0%)  |                             |
| Education degree of mother   |             |                             |
| Junior high school and below | 1099(24.9%) |                             |
| Senior high school           | 1342(30.3%) |                             |
| Characteristics                               | N (%) | Mean ± SD or median (range) |
|----------------------------------------------|-------|----------------------------|
| College                                      | 1138(25.7%) |
| University and above                         | 827(18.7%) |
| Weekly outdoor activity (hours)              |       |                            |
| < 7 h                                        | 426(9.6%) |
| 7 h-14 h                                     | 2382(53.9%) |
| 15 h-21 h                                    | 1291(29.2%) |
| 22 h-28 h                                    | 323(7.3%) |
| Weekly electronic devices period (hours)     |       |                            |
| < 10 h                                       | 281(6.4%) |
| 10 h-14 h                                    | 3736(84.5%) |
| >14 h                                        | 405(9.2%) |
| Weekly sleep duration (hours)                |       | 61.88 ± 7.31               |

**Relationship between AL, ALD and age**

There was a slow but steady increase in AL in children from age 3 to age 14, and after age 15, no statistically significant differences were found. Remarkable ascending trend were found in the students aged 6 to 7 and 11 to 12, in which an average of 0.39mm and 0.41mm were found (Figure 1A). The average AL in each group was 22.28± 0.70mmin preschoolers, 23.21± 0.98mm in primary school students, 24.35±1.17mm in junior high school students and 25.02± 1.18mm in senior high school students (P<0.001, Figure 1B). ALD also varied with ages, but ever since the age of 12, it showed no significant difference in either two consecutive years (Figure 1C). ALD was significantly different in the four groups (Figure 1D). High relevance was found in AL in both eyes (r=0.977, P<0.001), in which OD AL was 0.022mm longer than OS AL(P<0.001).

**UCVA and LCVA difference in both eyes**

OD UCVA was 0.004 worse than OS UCVA(P = 0.027) generally, while no significant difference was found in LCVA in both eyes. UCVA in preschoolers and primary school students were superior than that in junior and senior high school students; and the differences of UCVA between both eyes were higher than elder students. LCVA in primary and junior high school students were superior than that in senior high school students.
students and inferior than that in preschoolers. The differences of LCVA in junior and senior high school students were significantly higher than preschoolers and primary school students. The comparison of UCVA and LCVA between both eye could be obtained from Table 2.

Table 2
UCVA and lens-corrected VA(LCVA) in both eyes

|            | preschool | primary school | junior high school | senior high school |
|------------|-----------|----------------|--------------------|--------------------|
| **UCVA**   |           |                |                    |                    |
| OD         | 0.078(0.073 to 0.084) | 0.074(0.058 to 0.090) | 0.255(0.228 to 0.281) | 0.421(0.395 to 0.455) |
| OS         | 0.080(0.075 to 0.085) | 0.071(0.056 to 0.086) | 0.241(0.215 to 0.257) | 0.403(0.377 to 0.437) |
| Aniso-UCVA | P< 0.001  |                |                    |                    |
| **LCVA**   |           |                |                    |                    |
| OD         | 0.076(0.071 to 0.081) | 0.015(0.005 to 0.026) | 0.012(-0.004 to 0.027) | -0.022(-0.036 to -0.007) |
| OS         | 0.078(0.073 to 0.083) | 0.017(0.007 to 0.027) | 0.006(-0.010 to 0.021) | -0.031(-0.044 to -0.018) |
| Aniso-LCVA | P< 0.001  |                |                    |                    |

**Relating factors in AL and ALD**

A multivariate linear regression was conducted in all ages and four different age groups(Table 3). Female had a relatively shorter AL than that in male. “One of the parents was myopic”, “both parents were myopic” were associating with a longer AL in all the age groups compared with “none of the parents were myopic”. Weekly total media exposure of “10-14h” and “>14h” were associating with a longer AL compared with total media exposure of “<10h” in junior and senior high school students. Maternal educational degree of “University and above” were associating with a longer AL in junior high school students compared with those educational degree of “junior high school or below”. Weekly outdoor activities of “7-14h” and “14-21h” were associating with a shorter AL compared with “<7h” in primary school students.
Table 3
Associating factors in AL in the four groups (coefficients and 95% CI)

|                                | preschool   | primary school | junior high school | senior high school |
|--------------------------------|-------------|----------------|--------------------|--------------------|
| Gender                         | -0.519(-0.575 to -0.463) ‡ | -0.571(-0.676 to -0.466) ‡ | -0.685(-0.817 to -0.553) ‡ | -0.623(-0.798 to -0.448) ‡ |
| Parental myopia (ref: none was myopic) | 0.071(0.004 to 0.137) * | 0.045(-0.082 to 0.172) | 0.183(0.031 to 0.335) * | 0.062(-0.134 to 0.257) |
| One of the parents was myopic  | 0.068(-0.010 to 0.146) | 0.221(0.059 to 0.383) † | 0.266(0.034 to 0.498) * | 0.348(0.077 to 0.619) * |
| Both parents were myopic       | /           | 0.221(0.059 to 0.383) † | /                  | /                  |
| Outdoor activities (ref: less than 7 hrs/week) | 0.273(-0.525 to -0.021) * | / | / | / |
| 7–14 h                         | /           | /              | /                  | /                  |
| 14–21 h                        | /           | /              | /                  | /                  |
| >21 h                          | /           | /              | /                  | /                  |
| Total electric time (ref: less than 10 hrs/week) | 0.513(0.211 to 0.814) ‡ | 0.652(0.122 to 1.182) * | 0.544(-0.052 to 1.139) |
| 10–14 h                        | /           | /              | /                  | /                  |
| >14 h                          | /           | /              | /                  | /                  |
| Maternal educational level (ref: junior high school and below) | 0.047(-0.193 to 0.288) | 0.169(-0.087 to 0.425) | /                  | /                  |
| Senior high school             | /           | /              | /                  | /                  |
| College                        | /           | /              | /                  | /                  |

Statistical significance: *P<0.05, †P<0.01, ‡P<0.001.

Enter mode, which involved gender, average sleep duration(hours per week), average outdoor duration(four groups, ref: less than 7 hours per week), average electronic and TV duration(three groups, ref: less than 7 hours per week), parental myopic state(three groups, ref: none of them were myopes), education degree of father or mother(four groups, ref: lower than junior high school)
## Discussion

Axial length is one of the most valuable parameters extending with emmetropization. The annual ocular axial elongation of children in lower grade (age 6 to 9) was between 0.21 mm [11] and 0.70 mm [12]. In children aged 6 to 12, the annual axial elongation was 0.36 mm [13]. Apart from genetic factors, activities such as outdoor durations, indoor studying and near work [14] had been shown to affect refractive state as well.

Light was essential for ocular growth, and its coorelations with outdoor activites, sleep duration and myopia were widely investigated. Lieberman et al [15] first hypothesized that natural outdoor illumination and artificial indoor lighting might suppress melatonin secretion, interfering with sleep. Abbott et al[16] also found that prolonged outdoor duration for young adults would raise the secretion of melatonin in the morning, associating with sleep disturbance and daytime fatigue. The interact between sleep and myopia could also found its molecular mechanism in regulating circadian rhythms. High intensity of light exposure might inhibit myopia by stimulating the ipRGCs (intrinsically photosensitive retinal ganglion cells) which have synoptic connections with dopaminergic amacrine cells[17]. Dopamine then modulates melanopsin mRNA as to modify retinal circadian rhythms[18]. Besides, prolonged indoor light exposure did not exhibit any effect on myopia progression [19]. Kearney et al[20] found that in myopic young adults, the concentration of melatonin was higher than that in non-myopes. Ayaki et al[21] discovered that children with high myopia were more inclined to have sleep problems. Liu et al[22] further claimed that it was the late bedtime that took precedence over sleep duration as a predictive factor toward myopia progression. It could be concluded that melatonin is more abundant in myopes, but its effects on sleep...
might vary during different age periods. Insufficiency or excess of light exposure meant elaborate modifications of ocular growth based on several mechanisms.

Excessive “screen time” was significantly correlated with sleep deprivation in preschooler[23], school-aged children[24], adolescents [25] or young adults [26]. There were many studies ascribing myopia development to electronic devices usage or TV watching [27][28]. Using electronic devices or watching TV meant potent risk of eye overuse in near-distance, increasing accommodative spasm, or even lead to acute acquired comitant esotropia[29] in rare cases. We found that average axial length only correlated with TV duration and electronic devices usage in junior and senior high school students, and an average of 1 to 3 hours of outdoor duration per day was associated with a shorter axial length in primary school students. Guo et al[30] found that shorter time spent on outdoor activities and more time studying indoors were significantly correlated with a longer axial length in higher grade children (grade 4) instead of in lower grade children (grade 1). It could be inferred that ocular growth could be accelerated more prominently in elder children, and the outdoor durations might not be as effective a protective factor toward ocular length as other therapies such as orthokeratology[31][32] or atropine[33]. Apart from social factors, maternal educational degree and parental myopic background that implied genetic factors were also of importance for myopia or axial length prediction[34][35][36].

We noticed that only age was associated with ALD in primary school students, and other social as well as life habits were irrelevant in all the students. The harmfulness of anisometropia was well described in previous studies as for anisometropia and refractive error were the main amblyogenic factors toward children older than 3-year-old in China[37]. Kulp et al[38] found that in children aged 3 to 5, higher level of hyperopia was the risk factor for amblyopia and strabismus, which was also the case for studies conducted by Pascual et al[39]. The difference[40] in axial length between emmetropic eyes, myopic or hyperopic eyes were 0.80 mm and 0.44 mm, respectively. According to Patel et al[5], there was an average ALD of 1.57 mm(average 0.32 to 3.16 mm) in in children aged 7 to 8 who had anisometropic amblyopia(defined as the difference of spherical equivalent refraction > 3D). Hansen et al[41] also found that in amblyopic eyes(the difference of spherical equivalent refraction > 2D or axial length difference ≥ 1 mm), the mean axial length was 0.6 to 1 mm shorter than their counterparts. Limited by the cross-sectional nature of this study, we could not provide a precise conclusion on whether children with shorter or longer AL were more likely to have axial anisometropia, but the risk factors of anisometropia in different age groups should be underlined.

To date, researches that focused on axial anisometropia were listed in Table 4.
### Table 4
Reports on refractive/axial anisometropia during childhood and adolescence

| No. | Author, year | Age | Number | Highlights |
|-----|--------------|-----|--------|------------|
| 1   | Abrahamsson et al[42],1990 | 1 year until 4 years | 310 | Anisometropia was probably in a decline from infancy or was variable during emmetropization. |
| 2   | Tong et al[9],2006 | 7–9 years | 1979 | Anisometropia was correlated with bilateral axial length difference and was more prominent in myopic anisometropia |
| 3   | Chia et al[43],2009 | 9 years | 543 | No significant difference in spherical equivalent refraction and axial length between dominant eyes and nondominant eyes |
| 4   | Deng et al[44],2012 | 6-month 5 years, 12–15 years | 1827 | 1. The prevalence of anisometropia increases in children aged 12 to 15 2. Anisometropia was more prominent in myopes and hyperopes. |
| 5   | Donoghue[6],2013 | 6–7 years 12–13 years | 1050 | 1. Anisometropia was more common in children aged 12 to 13 with hyperopia ≥ +2DS 2. Anisometric eyes had greater axial length asymmetry than non-anisometric eyes |
| 6   | Deng et al[45],2014 | 9.29 ± 1.30 (at baseline) | 358(at baseline) | 1. In children who had more axial elongation over 13 years of observation, axial differences between both eyes (aniso-AL) were also more prominent. 2. The amount of anisometropia at commencement did not affect myopia progression. |
| 7   | Hu[10],2016 | 10.0 ± 3.3 years (4–18 years) | 6025 | 1. Refractive anisometropia was associated with longer axial length and larger interocular difference in axial length 2. Myopic anisometropia was correlated with paternal education and more time indoors while hyperopic anisometropia did not correlate with eye care habits. |
| 8   | Palamar et al[46],2016 | 11.09 ± 5.27 (4 to 33 months) | 42 | Axial length and mean keratometry were the leading causes of hyperopic anisometropia and rendered a total of 2.82D/mm and 2.14 D/D of refractive difference. |
| No. | Author, year         | Age                  | Number | Highlights                                                                 |
|-----|----------------------|----------------------|--------|-----------------------------------------------------------------------------|
| 9   | Hansen et al[41],2019| 11.7 ± 0.4 years     | 1335   | Six children that were axial anisometropia (intraocular difference in axial lengths ≥ 1 mm) were all amblyopic. |
|     |                      | (10.5–12.8 years)    |        |                                                                             |
| 10  | Bach et al[47],2019  | 30.62 ± 18.04 months | 165    | 1. Mean AL: 21.37 ± 1.03 mm                                                |
|     |                      | (3 months to 7 years) |        | 2. The steepest increase of AL was present in 10 months of age              |
|     |                      |                      |        | 3. No statistical difference was found in axial length between both eyes.    |

**Limitations**

There were several limitations in our study. First, the lack of cycloplegic refraction data prohibited us from comparing our findings with other myopic or anisometric epidemiological researches. However, we demonstrated a whole axial length distribution and bilateral axial length difference in students aged from 3 to 17, and also investigated the influencing factors in bilateral ocular development. Second, completing of axial length data in children younger than age three could further illustrate the average axial length progression. Third, longitudinal follow-up could provide more explicit cause-and-effect relationship of a certain kind of activity on monocular and binocular growth. Hence, a long-term follow-up visit was required.

**Conclusion**

In summary, axial length increased within age, and bilateral axial length difference was only significantly associated with age in primary school students. An average of 1 to 3 hours of outdoor durations per day and a longer sleep duration were associating with shorter axial length in primary school students, while longer total media exposure and parental myopic state were associating with a longer axial length in all children, especially for those in junior or senior high school.

**Abbreviations**

AL: Axial length; ALD: Axial length difference in both eyes; UCVA: Uncorrected visual acuity; LCVA: Lens-corrected visual acuity

**Declarations**

Not applicable.
Funding

Not applicable.

Availability of data and materials

The data and the analysis of the current study could be acquired from the corresponding authors if needed.

Authors contributions

XYM and MJC wrote the main manuscript text and prepared figure in the research; XYM and MJC made the statistical analysis; MXY, MJC and JHD made the interpretation of the data; JHD and XHS supervised and gave the critical revision of the manuscript. All authors reviewed and approved the manuscript.

Ethics approval and consent to participate

The study was approved by the Review Board of Fudan Eye and ENT hospital, adhering to the tenets of the Declaration of Helsinki. The purpose and the methods of the study were fully explained to parents or legal guardians, and informed consent was obtained from a parent and/or legal guardian as subjects under age 18.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Financial Disclosure

The authors had no commercial interest in any materials discussed in this article.

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