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Original Article

Correlation of eye movement parameters and refraction status in children at the age of 7-15 years

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Abstract: Objective: This study aimed to investigate the correlation between eye movement parameters (EMPs) and refractive status in children aging from 7 to 15 yrs, and to improve the prevention and treatment of juvenile myopia. Methods: 2205 children were enrolled and examined with retinoscopy after cycloplegia with tropicamide (0.5%). They were divided into myopia group (≤-0.50D), emmetropia group (+0.25--0.25D) and hypermetropia group (≥+0.50D). Furthermore, the patients in myopia group were divided into high myopia (≤-4.25D), moderate myopia (-2.25~-4.00D) and low myopia (-0.50~-2.00D) group. All children were examined with retinoscopy after cycloplegia with tropicamide (0.5%). The EMPs including AC/A ratio, accommodative lag, phoria at near and phoria at distance were identified with the phoropter. The correlations between EMPs and refraction status were analyzed, and the differences of the refraction status and EMPs in different age groups were identified. Results: AC/A ratio and accommodative lag in myopia group were higher than those in emmetropia and hypermetropia group (P<0.001). AC/A ratio in high myopia group was higher than those in low myopia group (P<0.001). The myopia degrees of refraction were positively correlated with AC/A ratios and age (r=0.146, P<0.001 and r=0.053, P=0.016). The age had no significant correlation with AC/A ratio (r=0.053, P=0.056), phoria at distance (r=-0.020, P=0.363), phoria at near (r=-0.011, P=0.619) and the accommodative lag (r=0.071, P=0.303). Conclusion: The children myopia may increase with more accommodative lag and high AC/A ratios, and there is an increasing tendency of the AC/A ratios which is consistent with more severe myopia degree.

Keywords: Children, refractive error, eye movement parameters, age

Introduction

Juvenile visual impairment is a global public health issue, which could continuously influence juvenile studies, communications, employments, and life qualities in lifetime. Several studies have demonstrated that the refractive error, especially the myopia is the common reason of juvenile poor visions [1]. The study of Zhao *et al.* [2] in China showed that refractive errors were as high as 89.5% in the visual impairments in children. A previous research also demonstrated that myopia was the major factor causing the visual impairments of the juvenile refractive errors [3]. The occurrence and development of myopia are associated with various factors such as genetic and environmental factors. However, the underlying mechanisms are unknown. In recent years, some studies showed that the occurrence and development of myopia were associated with the changes of all eye movement parameters (EMPs), including the increments of AC/A ratios, enlargements of the accommodative lag adjustment hysteresis values, short-distance external heterophoria tendency, long-distance internal heterophoria tendency and so on, and all these factors caused the hyperopic retina defocus state [4, 5]. The hyperopic optical defocus might make the tolerance of human eye for the vague images of the defocused retina change that promotes the scleral expansion and ocular axial extension, and leads to myopia developing [6].

The ability of human eyes to form far and near images on the retina is called adjustment, and it can enhance refractive ability through the convex crystalline lens or decreased curvature. In the adolescence, with the age increasing, the axial length and refractive ability of crystalline lens will also change, influencing the adjustment [6, 7]. The adjustment changes could directly cause the changes of the EMPs. Hence it was speculated that ages had certain influences on the changes of EMPs. Except China, many researchers also focused on the relationship between the EMPs and myopia, such as in UK [8], Japan [9, 10], the United States [11] and so on. However, all the results were different due to the different research methods, living environment, social economy, health, and nationalities. There were some available researches mainly carried out in the developed areas in China, such as Wenzhou [4], Anyang [12], Guangzhou [6], Jiangsu [13] and so on, but there is no large-scale epidemiological study yet.

The economic and living standard in the western China are relatively poor, and the juvenile myopia situations have not been taken seriously. There was little research about the EMPs analysis in children with refractive errors at different ages. Hence we enrolled the children at age of 7-15 years old, and investigated the relationships between the EMPs and age, which would be helpful to improve the prevention of juvenile myopia.

Methods

Patients

A total of 2205 children with refractive errors in the outpatient clinic of our hospital were enrolled from January 2012 to June 2015 according to the following inclusion criteria and exclusion criteria. Inclusion criteria were as follows: 1) the ages on the examination date were between 7 and 15 years old, and could be able to cooperate in the examinations; 2) the parents or legal guardians agreed with the examinations, and the written informed consent was obtained; 3) the refracting media had no opacities, and could be able to carry out the retinoscopy; and 4) no organic eye diseases. Exclusion criteria were as follows: 1) the eye diseases (for instance leucoma, cataract amotio retinae and so on) which resulted in the refracting media opacities or the pupil cannot be expanded hence influenced the retinoscopy; 2) patients of angle closure glaucoma and narrow angle had the mydriatic contraindications; 3) the allergic history for any components of mydriatic or the children had some eye discomfort after applying the medicine; 4) failed to examinations or without the permission from the legal guardians. Finally, 109 cases were excluded, in which 68 children with incomplete results and 41 children with seriously abnormal examination parameters. At last, 2096 patients were included for further analysis.

This study followed the guideline of the Helsinki declaration, and obtained the approval of the WHO Human Research Council, Chongqing Municipal Health Bureau as well as the Ethics Committee of our hospital (2012-20-SH). Consent to publish has been obtained from the guardian of the children.

Regular ophthalmologic examination

The regular ophthalmologic examination included using the regular slit lamp to exclude leucoma, cataract amotio retinae which resulted in the refracting media opacities, and using intraocular pressure measurement (TOPCON CT-80) to carry out the mydriatic contraindications.

Static optometry

For the eyes of one child, first of all, the 0.5% tropicamide + sodium hyaluronate were used to paralysis the medicines, one drop for one time in every 10 minutes, and 3 times in total. The sac area was pressed for about 5-10 minutes after last administration of the mydriatic, in order to reduce the systemic absorption of the medicines. The retinoscopy was carried out by using the strip light ophthalmoscope (Model: YZ24; Six Six Vision Corp, Suzhou, China).

Groups

A total of 2096 children were enrolled and divided into myopia group (≤-0.50D) (n=1 897), emmetropia group (+0.25--0.25D) (n=96) and hypermetropia group (≥+0.50D) (n=103). Furthermore, the patients in myopia group were divided into high myopia (≤-4.25D) (n=228), moderate myopia (-2.25--4.00D) (n=774) and low myopia (-0.25--2.00D) (n=895) group. In this study, the refractive degree was expressed by the spherical equivalent refraction (SER),

Table 1. Spherical equivalent refraction and parameters (AC/A ratio, accommodative lag, phoria at near and phoria at distance) among the myopia group, emmetropia group and hyperopia group

	N	Spherical equivalent refraction (D)	Response AC/A Ratio (Δ//D)*	Phoria at distance (Δ)	Phoria at near (Δ)	Lag of accommodation (D)*
Myopia	1897	-2.527±0.033	3.690±0.057	0.247±0.069	-0.527±0.033	2.648±0.060
Emmetropia	96	0.009±0.331	2.450±0.331	0.106±0.375	0.206±0.628	2.529±0.089
Hyperopia	103	2.176±0.129	0.782±0.221	1.848±0.260	0.875±0.436	0.555±0.065

Notes: *means the parameter of the different groups had significantly difference between the others ($P<0.05$) ANOVA, least-significance-difference Method. There are significant differences in the AC/A ratio between the myopia group and emmetropia group (P=0.043), myopia group and hypermetropia group (P=0.032). There are significant differences in the AC/A ratio between the myopia group and emmetropia group (P=0.028), myopia group and hypermetropia group (P=0.013). There were no significant differences of the long-distance heterophoria and short-distance heterophoria among the three groups.

according to the following formula: SER= spherical refraction +1/2 column refraction.

Measurement of the horizontal heterophoria

VonGrafe on the phoropter was used to measure the horizontal heterophoria of the long-distance 6 m and short-distance 40 cm, which represented the long-distance heterophoria and short-distance heterophoria, respectively ("+" means the internal heterophoria, and "-" means the external heterophoria).

Calculation of AC/A ratios

After measures of the horizontal heterophoria, the AC/A ratios were calculated according to the following formula: AC/A ratio =(short-distance convergence demand)-(long-distance heterophoria) + (short-distance heterophoria)/ near accommodative stimulus.

At 40 cm, the short-distance convergence demand was PD/0.4 m, in which PD represented the pupil distance with the unit of cm. Near accommodative stimulus =1/0.4=2.50D.

Measurement of the adjustment hysteresis (FCC method)

On basis of the subjective refraction, the fused cross cylinder was used to measure the hysteresis with subjective adjustment. The indoor lighting was reduced to obscuration, and the eyes were added with the ±0.50D cross cylinder at the near PD. the FCC test-object was placed at 40 cm in front of the eyes, and the child was asked to report which of the horizontal line and the vertical line was more distinct. If the horizontal was distinct, normal lens were added until the horizontal line, the vertical line were both distinct, and the amount of the added normal lens represented the adjustment hysteresis.

Data collection and processing

In all age groups, the refractive degree distributions of the left and right eyes were similar (P>0.05). The distribution parameters of refractive degree were expressed by the average refractive degrees (mean ± SD). Because the extreme refractive degree was rare in the right eye, it could represent the general tendency well. The statistics and analysis for the EMPs of the right eyes were carried out in this study. In order to reduce the errors, the medicine applying, retinoscopy, measures of the horizontal heterophoria, measures of AC/A, measures of the adjustment hysteresis values as well as the data processing were undertaken in six patients. Each step was completely processed by the same doctor, and the study followed the "triple blind" principle. These data were reviewed before the input, and two authors were responsible for the input of the data so as to guarantee the accuracy.

Statistical analysis

SPSS 20.0 software was used to carry out the statistic analysis. The various EMPs in groups with different refractive degrees were compared with the one-way ANOVA and least-significance-difference method (LSD). *P* values were two-sided with a level of significance of 0.05. When there were statistically significant differences in various groups, the comparisons were carried out with the LSD multiple comparison method. The correlation coefficient of Pearson was used to evaluate the correlations among the EMPs and the refractive state as well as age.

Table 2. Correlations analysis of Spherical equivalent refraction and age with parameters

	Spherical equivalent refraction (D)		Response AC/A Ratio (Δ//D)		Phoria at distance (Δ)		Phoria at near (Δ)		Lag of accommodation (D)	
	r	p	r	p	r	p	r	p	r	p
Ages (yr)	-0.027	P<0.001	0.053	0.056	-0.020	0.363	-0.011	0.619	0.071	0.303
SER (D) of all the patients			-0.172	0.309	0.025	0.248	0.012	0.586	-0.024	0.281
SER (D) of myopia group			0.269	0.024	-0.007	0.760	-0.017	0.542	0.013	0.572

Notes: SER, spherical equivalent refraction.

Table 3. Spherical equivalent refraction and parameters among all groups

	N	Spherical equivalent refraction (D)	Response AC/A Ratio (Δ/D)*	Phoria at distance (Δ)	Phoria at near (Δ)	Lag of accommodation (D)
High myopia	228	-5.172±0.042	3.558±0.141	0.357±0.249	-0.831±0.412	0.572±0.031
Moderate myopia	774	-2.692±0.024	3.443±0.096	0.266±0.144	-0.272±0.237	0.573±0.018
Mild myopia	895	-1.334±0.026	3.236±0.072	0.202±0.154	0.505±0.253	0.539±0.019

Notes: *means the parameter of the different groups had significantly difference with the others (*P*<0.05) ANOVA, least-significance-difference Method. There were significant differences in the AC/A ratio between the high myopia group and the low myopia group (P=0.019). There were no significant differences of the long-distance heterophoria, adjustment hysteresis, and Short-distance heterophoria among the three groups.

Results

General data

In 2205 cases meeting the inclusion criteria, 109 cases were excluded in which 68 children with incomplete results and 41 children with seriously abnormal examination parameters. At last, 2096 patients were included aging from 7 to15 years old. And the male/female ratio was 1.08/1.00.

The refractive degree scope of all included objects after the tropicamide mydriasis was +3.00D- -9.00D, the absolute value of astigmatism was less than 5.00D, and the refractive staggers of both eyes were less than 1.00D.

Comparisons of EMPs in myopia, emmetropia and hypermetropia groups

AC/A ratio was the highest in the myopia group, followed by the emmetropia group and then the hypermetropia group (F=85.904, P<0.001) (**Table 1**). There were no significant differences in the AC/A ratio between the emmetropia group and hypermetropia group (P>0.05).

Adjustment hysteresis value was the highest in the myopia group, followed by the emmetropia group and then the hypermetropia group (F=779.874, P<0.001). There were no significant differences of the adjustment hysteresis value between the emmetropia group and hypermetropia group (P>0. 05).

The three groups were all expressed as the long-distance internal heterophoria tendency, and the differences were not significant (F= 3.059, P=0.054).

The emmetropia group and the myopia group had the short-distance internal heterophoria tendency, and the myopia group had the external heterophoria tendency; however, there were no significant differences (F=0.832, P=0.435) (**Table 1**). There were no significant correlations among the AC/A ratios (r=-0.172, P=0.309), adjustment hysteresis values (r=-0.024, P= 0.281), long-distance heterophoria (r=-0.024, P=0.281), short-distance heterophoria (r= 0.025, P=0.248) and the spherical equivalent refraction (r=0.012, P=0.586) (**Table 2**).

Comparisons of EMPs in high, moderate and low myopia group

AC/A ratio was the highest in the high myopia group, the second in the moderate myopia group and the lowest in the low myopia group (P<0.001). However, there were no significant differences between the high myopia group and moderate myopia group, as well as the moderate myopia group and low myopia group (P>0.05). There were no significant differences among three groups (F=591, P=0.525) (**Table**

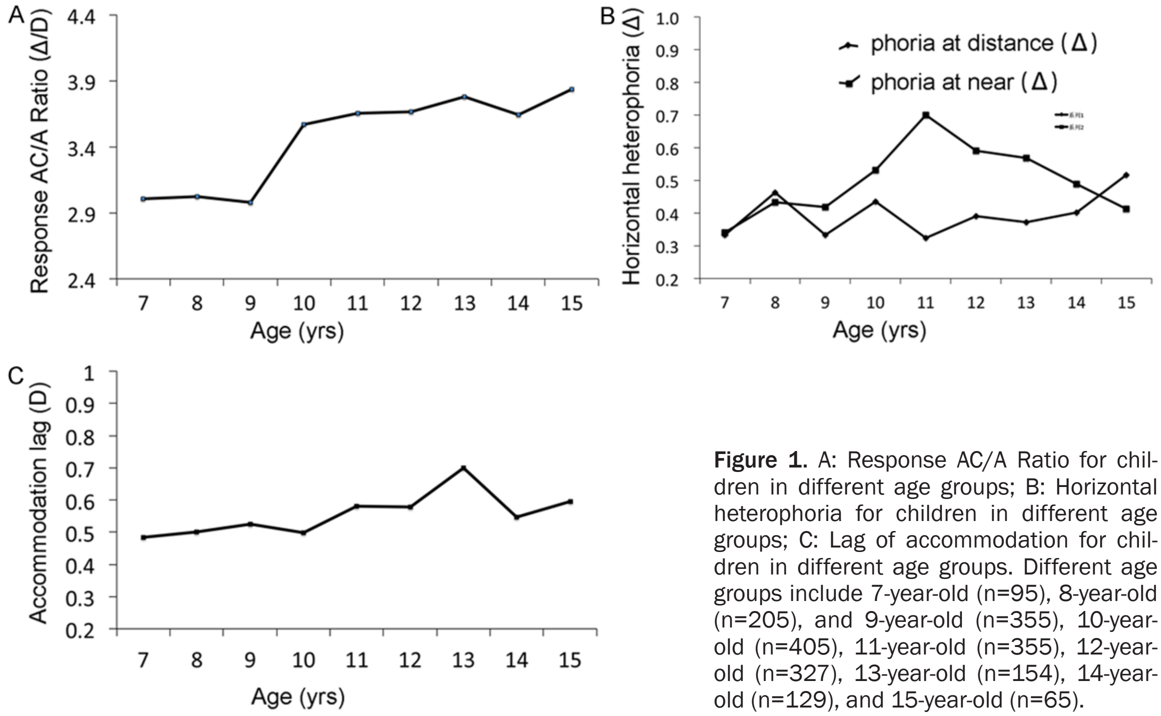

Figure 1. A: Response AC/A Ratio for children in different age groups; B: Horizontal heterophoria for children in different age groups; C: Lag of accommodation for children in different age groups. Different age groups include 7-year-old (n=95), 8-year-old (n=205), and 9-year-old (n=355), 10-year-old (n=405), 11-year-old (n=355), 12-year-old (n=327), 13-year-old (n=154), 14-year-old (n=129), and 15-year-old (n=65).

3) in terms of the adjustment hysteresis values, nor was the long-distance heterophoria (F=0.077, P=0.926). The low myopia group had the short-distance internal heterophoria tendency, and the high and moderate myopia group had the short-distance external heterophoria tendency. The short-distance external heterophoria tendency in the high myopia group was more significant than that in the moderate myopia group (F=0.989, P=0.372). The myopia refractions were positively correlated with the AC/A ratios significantly (r=0.269, P=0.024). There were no significant correlation between the myopia refractions and adjustment hysteresis values, long-distance heterophoria or short-distance heterophoria (**Table 2**).

Refractive condition and EMPs in children with different ages

AC/A ratios had the increasing tendency after 10 years old, and afterwards they were gradually becoming stable (**Figure 1A**). The short-distance heterophoria, long-distance heterophoria as well as the adjustment hysteresis values were relatively stable at the ages of 7-15 years old, and the short-distance and long-distance heterophoria were all expressed as the internal heterophoria (**Figure 1B** and **1C**).

The ages were negatively correlated with the spherical equivalent refraction (r=-0.227, P<0.001). There were no significant correlations between age and AC/A (r=0.053, P=0.056), long-distance heterophoria (r=-0.020, P=0.36), short-distance heterophoria (r=-0.011, P=0.619) or the adjustment hysteresis values (r=0.071, P=0.303) (**Table 2**).

Discussions

In this study, we found that the AC/ratio in myopia group was higher than those in emmetropia and myopia groups, and there was an increasing tendency of AC/A ratio consistent with the raising myopia degrees. This could be in order to keep the binocular function and to improve the efficiency and synchronism of the innervations when focusing on the short-distance test-object. The eyeball convergence movements are enhanced, but the contractility of the ciliaris is exhausted after the long-time focusing. However the contractility of the ciliaris is decreased that leads to the decrease of the adjustment response [14]. It results the unbalance between adjust and convergence movement that increases the AC/A ratio [15]. At the same time, this unbalance will cause the defocusing retina images, and make the ocular axial grow towards the myopia [16]. Furthermore it could also result the development of myopia. The studies in recent years show that AC/A ratio is related to the refractive error, and the myopia patients have higher AC/A ratios than the emmetropia [8, 17]. The increasing tendency of AC/A ratio will be more severe with the deepening of myopia degrees [6]. All of them are consistent with our results.

Our research also found that AC/A ratio at the age of 9-10 years old had the increasing tendency, and afterwards became stable. Some scholars believed that AC/A ratios had not obviously change with the age, but the unbalances of AC/A ratio in myopia had the increasing tendency with the age [17]. In the adolescence, as the children growing up, the axis oculi and lens are also at the rapid growth period [7, 8, 18]. The ocular axial grows longer, the lens grows flat, and the curvature radius is increased, which causes the decrease of the eye refractive and adjustment ability [7]. The decrease of the adjustment ability could cause the unbalance between the adjustment and the convergence movement, and increase the AC/A ratio. Besides, children with age of 10 years old in China are just entering the third grade of the primary schools. With hard study, the short-distance homework time in children with age of 10 years old is much longer than younger children. The contractility of the ciliaris is exhausted and the convergence force is decreased, which leads to the unbalance between the adjustment and convergence, and increases the AC/A ratio [19].

This research also found that the lag of accommodation in the myopia group is much higher than those in the emmetropia and hypermetropia groups, which represented that the adjustment responses in the myopia group were weaker than the hypermetropia group. The reasons might be that the myopia retina stays at the defocusing state for a long time, and the continuous constriction of the ciliaris causes the muscle fatigue [20]. The fatigue can cause myasthenia and degenerative changes of the musculi ciliaris, leading to a decrease of accommodation and adjustment hysteresis [21]. Some scholars also believed that the sensibilities of the nervus in myopia patients for the retina blurs and the perceptivities were both decreased [22]. The nerve impulse from retina cannot be transmitted to the ciliary ganglion timely, so the muscle contraction and change of lens curvature are delayed. This decrease of accommodation can lead to the adjustment hysteresis [6, 7]. At the same time, the lens blurs could cause the retina blurs to produce the growth factors and adjust the extension of the axis oculi [23]. When this adjustment scope was exceeded, the axis oculi is abnormally enlarged, which causes the disturbances of the coordination among various refractive components of the eyeballs, and leads to the occurrence and development of myopia [24]. The results of many researches in the recent years showed that compared to the emmetropia patients, the adjustment responses of the myopia children were weaker, which made that after the test-object imaging on the retina, in order to get the clear retina images, the eyeballs develop towards the myopia extension, and lead to the development of myopia [8, 25]. This is similar to our results.

This study found that the moderate and high myopia groups have the short-distance external heterophoria tendency, but the low myopia group, the emmetropia group and hypermetropia group all showed the short-distance internal heterophoria tendency. In the short-distance works, the demands for convergent movement increase and it will also cause the increase of adjustment responses. The adjustment is accomplished through the muscle contractions of the ciliaris causing the changes of the lens shapes and the curvatures [26]. If the myopia lasts for long time, the muscle tone of the continuously contractile ciliaris will decrease, and the adjustment response will descend, and meanwhile cause the weakening of the convergent movement and lead to the occurrence of the external heterophoria [27]. Seidel *et al.* [28] and Mutti *et al.* [9] also found that the short-distance heterophoria of myopia was mainly manifested as the external heterophoria, which was similar to the results of our researches. Some literatures reported that the myopia could be possibly manifested as internal and external heterophoria tendency in the short-distance works [15, 29]. Chung and Chong [30] and Lu *et al.* [4] found that the children myopia with the internal heterophoria tendency were used to keep the binocular function and reduce the adjustment convergence and it requires the relaxing adjustment, and the decrease of the adjustment responses cause the defocusing retina, and furthermore to promote the progresses of the existing myopia. The reasons leading to the differences between our results and his results might be that the research subjects of Chung and Chong [30] are all the myopia children in Southeast regions with lower population density. The subjects of Lu *et al.* [4] were myopia adults in the developed areas in China. While our research subjects were children at the ages of 7-15 years old, including the myopia, emmetropia and hypermetropia in the less developed western areas of China, and the sample volume was much larger.

Overall, the development of children myopia might be related to the increment of the adjustment hysteresis values and the high AC/A ratios. The AC/A ratios have the rising tendency with the myopia deepening, specifically in children at the ages of 9-10 years. Hence, the myopia can be identify at the early stage by the follow-up for AC/A ratios and the adjustment hysteresis values, and myopia can be prevented with some personalized treatments. This is just a cross-sectional study, and we will carry out the prospective cohort study to confirm the relations between the juvenile myopia and the EMPs. Furthermore, we will balance the sample size at all ages to improve further studies and early prevention of myopia.

Disclosure of conflict of interest

None.

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