

Original Article

Factors influencing refractive status distribution and amblyopia in preschool children with low vision

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Abstract: Objective: To reveal the distribution characteristics of refractive status of preschool children with low vision, analyze the independent risk factors of amblyopia (AMB), and build a risk prediction model, so as to provide a basis for early screening and precise intervention. Methods: We enrolled 180 preschoolers (3-6 years old) with low vision from January 2023 to December 2024. All of the participants underwent standardized examinations, with their refractive status and visual characteristics recorded. Subsequently, a univariate analysis was conducted to identify differences in demographic characteristics, perinatal factors, environmental behaviors, and refractive state between AMB and non-AMB children, followed by regression coefficient-based AMB risk assessment model construction, with model performance validated by receiver operating characteristic (ROC) curves. Results: Hyperopia was dominant in children with low vision. With an increase in age, the proportion of hyperopic refractive error gradually decreased. AMB occurred at an overall incidence of 40.00% (72/180) among our cohort, with the prevalence being dominant in the 4-5-year age group. According to multivariate analysis, parental myopia, time spent on close-range eye use, and refractive status were independent risk factors for AMB. Through internal validation, it was found that the prediction model had clinical application value in AMB screening. Conclusion: The main refractive abnormality in preschool children with low vision is hyperopic refractive error, which is also the core risk factor for AMB. The risk prediction model we constructed can effectively identify high-risk groups, providing an efficient tool for early clinical screening.

Keywords: Preschool children, refractive status, amblyopia, parental myopia, related factors

Introduction

The preschool stage is a crucial window period for children's visual development. If poor vision (binocular best corrected visual acuity [BCVA] lower than the normal range for age) during this period is not promptly intervened upon, approximately one-third may progress to amblyopia (AMB), resulting in permanent visual function impairment and affecting learning, life, and mental health [1]. Refractive errors (e.g., hyperopia, astigmatism, anisometropia), the primary cause of low vision in preschoolers (approximately 70%-80%), are closely related to the occurrence of AMB [2]. Among them, moderate-to-high hyperopia, high astigmatism, and anisometric AMB account for the highest proportion [3]. Therefore, clarifying the distribution characteristics of refractive status, the occurrence status of AMB, and influencing factors in this population is needed to facilitate screening and intervention.

Research has outlined the epidemiological profile of the refractive status of preschoolers: hyperopia constitutes around 15%-25% (decreasing with age), astigmatism occupies a proportion of about 10%-18%, and myopia is detected in fewer than 5% [4]. The overall incidence of AMB approximates 2%-4%, dominantly anisometropia and strabismus [5]. However, current research has focused insufficiently on the high-risk group of children with low vision, lacking systematic investigations into the quantitative correlation between their refractive status and the occurrence of AMB [6, 7]. Meanwhile, the research on influencing factors was mostly limited to a single variable (such as genetics, history of premature birth), rather than conducting a comprehensive assessment by integrating multiple dimensions such as environmental factors and eye usage behaviors [8, 9].

Hence, this study retrospectively analyzed the refractive status (hyperopia, myopia, cylinder

[CYL] power distribution) and the incidence of AMB in preschoolers with low vision in China. In addition, demographic characteristics, perinatal factors, as well as environmental and behavioral factors, were integrated to build a multivariate analysis model to clarify the independent risk factors for AMB. This is the first time to specifically target “children with low vision”, combined with refractive parameters and diagnostic criteria of AMB, to quantify the predictive value of refractive errors on AMB. We pioneered the use of emerging environmental variables such as “digital device usage time” and “outdoor activity intensity”, making up for the neglect of traditional research regarding these factors. The results are expected to provide evidence-based support for the formulation of guidelines for vision screening of preschool children, as well as for optimizing the early intervention strategies for AMB, thus reducing AMB-induced disability.

Materials and methods

Research nature and design

This study, designed as a single-center retrospective analysis, collected the clinical data of preschoolers with low vision admitted to Jinhua Municipal Central Hospital from January 2023 to December 2024. By systematically analyzing the distribution of refractive status, the occurrence of AMB, and the related contributors, we aimed to provide a basis for early intervention. Following screening based on the inclusion/exclusion criteria, 180 participants were included. This study was approved by the Ethics Committee of Jinhua Municipal Central Hospital.

Inclusion/exclusion criteria

Inclusion criteria: (1) Age: 3-6 years old; (2) Binocular BCVA < normal range for age (≥ 0.5 , ≥ 0.6 , ≥ 0.7 , and ≥ 0.8 for children aged 3, 4, 5, and 6 years, respectively) [10]; (3) Completeness of the standard examinations in our hospital: mydriatic optometry (mydriasis was performed with 1% compound tropicamide eye drops, 2 drops per eye, 5 minutes apart, and optometry was performed after 30 minutes of instillation), visual assessment (Lea Symbols Chart), AMB diagnosis (① Binocular best corrected visual acuity (BCVA) difference ≥ 2 lines; ② The monocular BCVA below the normal range of age (3 years old ≥ 0.5 , 4 years old ≥ 0.6 , 5 years old

≥ 0.7 , 6 years old ≥ 0.8), and the visual acuity did not improve more than 1 line after wearing appropriate corrective glasses for 3 months (ineffective correction); ③ If the BCVA of one eye is lower than the normal range of age but the difference between the two eyes is less than 2 lines, after excluding congenital eye diseases and nervous system diseases, if the correction is ineffective, it is also diagnosed as amblyopia) [11]. Exclusion criteria: (1) Low vision caused by congenital eye diseases (congenital cataract, glaucoma, etc.) or neurological disorders (e.g., cerebral palsy, optic atrophy); (2) Previous AMB treatment (spectacle prescription, occlusion therapy, visual training, etc.); (3) Incomplete data (lack of data on refraction, vision records, and/or key influencing factors).

Data collection

Through the electronic medical records, we extracted the following information of the participants: basic information: age, sex, place of residence, parental history of myopia [Parental myopia was defined as binocular spherical equivalent ≤ -0.50 D (pseudomyopia and temporary vision loss were excluded)]; Perinatal factors: history of premature delivery, birth weight, and neonatal asphyxia history; Environmental and behavioral factors: A pre-experimental structured questionnaire was used to collect data (Cronbach's $\alpha=0.82$). Daily outdoor activity time [Excluding the outdoor time on transportation to and from school, only the time of active activities under unblocked natural light (such as outdoor games, sports, walking, etc.) was recorded. The questionnaire item: The average time of children's outdoor natural light activities in the past 7 days (excluding on the way to/from school)], near-distance eye use time [Subdivide the activity types (paper reading, electronic device use, craft/painting, etc.), record distributed continuous data the duration separately and sum up. Sample questionnaire items: In the past 7 days, on average, children spent on paper reading per day. Electronic device use is divided into mobile phone, tablet, TV, etc., and segmented entries are used to facilitate accurate recording], lighting conditions; Refraction and vision-related indices: naked vision (LogMAR), BCVA (LogMAR), spherical equivalent (SE), CYL (astigmatism), anisometropia (binocular SE difference). The stan-

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Table 1. Refractive status of patients in this study

Status	n	Percentage
Hyperopic refractive error	110	61.11% (of 180 patients)
mild	81	73.63% (of 110 patients)
moderate	19	17.27% (of 110 patients)
severe	10	9.09% (of 110 patients)
Astigmatic refractive error	42	22.22% (of 180 patients)
mild	26	61.90% (of 42 patients)
moderate	11	26.19% (of 42 patients)
severe	5	11.90% (of 42 patients)
Anisometropia	22	12.22% (of 180 patients)
Myopic refractive error	6	3.33% (of 180 patients)
Axis of astigmatism		
Astigmatism with the rule	28	66.67% (of 42 patients)
Astigmatism against the rule	10	23.81% (of 42 patients)
Oblique astigmatism	4	9.52% (of 42 patients)

dard of refractive error [12]: hyperopia: mild + 0.50~ + 3.00 D, moderate + 3.25~ + 5.00 D, high >5.00 D. Astigmatism: mild \leq 1.50 D, moderate 1.75-2.50 D, high >2.50 D.

Endpoints

The characteristics of refractive status and parameters of preschoolers with low vision were analyzed. Based on the diagnostic results of AMB, the children were grouped (AMB vs. Non-AMB) to analyze the factors influencing AMB. Finally, a novel AMB risk assessment model was established based on the analysis results, and its diagnostic effectiveness was verified.

Statistical methods

Data analysis and processing were conducted with SPSS 32.0. The comparison of categorical variables [n (%)] used chi-square tests; for four-fold tables, when there were data in each cell with a theoretical frequency less than 5, the Fisher's test was used. Continuous variables were subjected to Shapiro-Wilk testing. Normally distributed continuous data ($x \pm s$) were analyzed by independent samples t-tests between groups and by repeated measures analysis of variance plus the Bonferroni test among multiple groups; skewed data were presented as [M(P25, P75)], with comparisons made with the Mann-Whitney U test (between groups) and the Kruskal-Wallis H test (among multiple groups). Logistic regression analysis was used for the identification of related fac-

tors, and ROC curve analysis was conducted to determine diagnostic value. Statistical significance was set at $P < 0.05$.

Results

Distribution of refractive status in preschoolers with low vision

According to statistics, hyperopia was the main type of refractive error among the low-vision children studied, and the proportions of astigmatism and refractive anisometropia were the same. Astigmatic ametropia was mainly mild (73.63), and anisometropia was also

dominantly mild in severity. Myopic ametropia accounted for a relatively small proportion, with only 6 cases (Table 1).

Differences in refractive status across age groups

Age-based subgroup analysis indicated that the proportion of hypermetropia decreased gradually with the increase of age (70.27% in 3-year-olds, 65.52% in 4-year-olds, 61.36% in 5-year-olds, 46.34% in 6-year-olds), with a significant linear downward trend (trend $\chi^2=8.96$, $P=0.003$). The proportion of severe hyperopia in 6-year-olds (21.05%) was significantly higher than that in 3-year-olds (7.69%). However, the proportion of astigmatism was relatively evenly distributed across all age groups (20.45%-25.86%, $P > 0.05$), and the proportion of anisometropia showed a significant linear upward trend with age (trend $\chi^2=9.85$, $P=0.002$), from 5.41% in 3-year-olds to 26.83% in 6-year-olds (Table 2).

Univariate analysis of factors influencing the occurrence of AMB

In this study, AMB was diagnosed in 72 (40.00%) children. By comparing the various data of children with AMB and those without, it was observed that the proportions of 4-5-year-olds, parents with myopia, and premature infants were higher in AMB-affected preschoolers ($P < 0.05$). In terms of environmental factors, a greater number of AMB children had daily outdoor activities < 2 h and near-distance eye use

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Table 2. Differences in refractive status among children of different ages

	3 years (n=37)	4 years (n=58)	5 years (n=44)	6 years (n=41)
Mild	33 (97.06)	56 (96.55)	37 (84.09)	29 (70.73)
Moderate	3 (8.11)	3 (5.17)	5 (26.32)	8 (19.51)
Severe	1 (2.70)	3 (5.17)	2 (4.55)	4 (9.76)
Hyperopic refractive error	26 (70.27)	38 (65.52)	27 (61.36)	19 (46.34)
Astigmatic refractive error	9 (24.32)	15 (25.86)	9 (20.45)	9 (21.95)
Anisometropia	2 (5.41)	4 (6.90)	5 (11.36)	11 (28.83)
Myopic refractive error	0 (0.00)	1 (1.73)	3 (6.82)	2 (4.88)

Table 3. Univariate analysis affecting AMB

Factor	non-AMB (n=108)	AMB (n=72)	χ^2	P
Age				
3	27 (25.00)	10 (13.89)	3.266	0.071
4	28 (25.93)	30 (41.67)	4.901	0.027
5	20 (18.52)	24 (33.33)	5.134	0.024
6	33 (30.56)	8 (11.11)	9.286	0.002
Sex			0.370	0.543
boys	52 (48.15)	38 (52.78)		
girls	56 (51.85)	34 (47.22)		
Parents myopia			4.551	0.033
yes	44 (40.74)	41 (56.94)		
no	64 (59.26)	31 (43.06)		
Premature infants			4.515	0.034
yes	26 (24.07)	28 (38.89)		
no	82 (75.93)	44 (61.11)		
Daily outdoor activities			5.753	0.017
<2 h/d	28 (25.93)	31 (43.06)		
≥2 h/d	80 (74.07)	41 (59.94)		
Time spent on close-range eye use			6.000	0.014
>1 h/d	52 (48.15)	48 (66.67)		
≤1 h/d	56 (51.85)	24 (33.33)		
Refractive state				
Hyperopic refractive error	58 (53.70)	52 (72.22)	6.234	0.013
Astigmatic refractive error	30 (27.78)	12 (16.67)	2.981	0.084
Anisometropia	16 (14.81)	6 (8.33)	1.692	0.193
Myopic refractive error	4 (3.70)	2 (2.78)	0.115	0.735

Note: AMB, Amblyopia.

time >1 h per day ($P<0.05$), while there was no difference in lighting conditions ($P>0.05$). In terms of refractive status, the proportion of AMB children with hyperopic refractive error was higher than that of non-AMB children ($P<0.05$) (**Table 3**).

Multivariate analysis of determinants of AMB

We assigned values to the above-mentioned significant single-factor indicators as depen-

dent variables (**Table 4**). Logistic regression analysis (mode: Forward LR) was carried out to show whether AMB occurred as an independent variable. The output indicated that age, preterm infants, and daily outdoor activity time were not independent factors affecting AMB ($P>0.05$). Instead, parental myopia (OR=0.416, 95% CI=0.185-0.937), time spent on close-range eye use (OR=0.412, 95% CI=0.203-0.837), and refractive status (OR=0.501, 95%

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Table 4. Assignment table

Factor	Assignment
Groups	Non-AMB = 1, AMB = 2
Age	Analysis was performed using raw data
Parents myopia	Yes = 1, no = 2
Premature infants	Yes = 1, no = 2
Daily outdoor activities	>2 h/d=1, ≤2 h/d=2
Time spent on close-range eye use	>1 h/d=1, ≤1 h/d=2
Refractive state	Hyperopic refractive error = 1, Other = 2

Note: AMB, Amblyopia.

Table 5. Multivariate analysis affecting AMB

Factor	B	S.E.	Wals	P	OR	95% CI	
						Lower limit	Upper limit
Age	-0.06	0.16	0.139	0.709	0.942	0.688	1.289
Parents myopia	-0.876	0.414	4.485	0.034	0.416	0.185	0.937
Premature infants	-0.491	0.331	2.207	0.137	0.612	0.32	1.17
Daily outdoor activities	-0.646	0.365	3.136	0.077	0.524	0.257	1.071
Time spent on close-range eye use	-0.887	0.362	6.016	0.014	0.412	0.203	0.837
Refractive state	-0.691	0.339	4.146	0.042	0.501	0.258	0.974

Note: AMB, Amblyopia; B, Regression Coefficient; SE, Standard Error; OR, Odds Ratio; CI, Confidence interval.

Table 6. Results of regression analysis after excluding non-independent factors

Factor	B	S.E.	Wals	P	OR	95% CI	
						Lower limit	Upper limit
Parents myopia	-0.868	0.41	4.49	0.034	0.42	0.188	0.937
Time spent on close-range eye use	-0.867	0.344	6.362	0.012	0.42	0.214	0.824
Refractive state	-0.747	0.332	5.051	0.025	0.474	0.247	0.909
Constant	0.754	0.336	5.027	0.025	-	-	-

Note: B, Regression Coefficient; SE, Standard Error; OR, Odds Ratio; CI, Confidence interval.

CI=0.258-0.974) independently influenced AMB (P<0.05) (Table 5).

AMB risk model establishment and performance validation

Another regression analysis was conducted after eliminating the above-mentioned non-independent factors. Based on the regression coefficient (β) of each independent factor, we established a quantitative analysis model for AMB risk assessment: Joint model=0.754 + (-0.868 × Parents' myopia) + (-0.867 × Time spent on close-range eye use) + (-0.747 × Refractive state) (Table 6). The Hosmer-Lemeshow (HL) goodness-of-fit test for the logistic regression model showed a non-significant result (χ²=6.25, P=0.615), indicating a good fit of the model to the actual data. Baseline balance

testing was performed on the training set (n=126) and validation set (n=54) after 7:3 random grouping, and the results showed no significant differences in demographic characteristics, refractive status, or environmental factors between the two sets (all P>0.05), confirming the reliability of model validation. The results of ROC curve analysis revealed that the model exhibited a good prediction (training set: AUC=0.664, validation set: AUC=0.761) effect for AMB across the datasets (Figure 1 and Table 7).

Discussion

Through a retrospective analysis of the clinical data of 180 preschoolers with low vision, this study revealed the distribution characteristics of refractive status and the key patterns of

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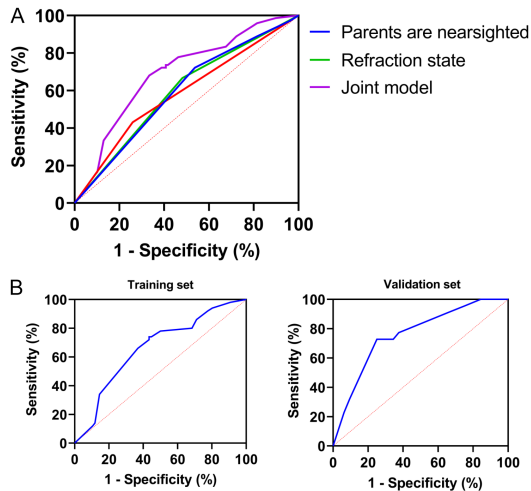


Figure 1. Analysis of the diagnostic efficacy of the joint model for AMB. A. An AMB assessment model was established based on the AMB related factors. B. After all subjects were assigned to the training set and validation set, ROC curve analysis was performed again to determine the diagnostic effect of the joint model on AMB. Note: AMB, Amblyopia; ROC, Receiver operating characteristic.

AMB occurrence in this patient group. Hyperopia was found to be the major type of refractive error in low-vision preschoolers, followed by astigmatism and anisometropia, while myopia accounts for less than 5%. The overall incidence of AMB was 40.00%, with 4-5-year-olds being the high-risk age group and severe AMB accounting for the highest proportion. Based on multivariate findings, parental myopia, time spent on close-range eye use, and refractive status were independent determinants of AMB. Based on this, this study successfully constructed an AMB risk prediction model, providing a quantitative tool for early clinical screening.

This study confirmed that hypermetropia was dominant in preschoolers with low vision. This discovery is supported by the form deprivation theory proposed by Meng et al.: High hyperopia leads to blurred retinal imaging, which exceeds the form deprivation threshold in the critical visual development period (3-6 years old), and inhibits synaptic pruning and functional differentiation of macular neurons, ultimately causing AMB [13]. It is worth noting that the proportion of hyperopia in this study decreased with age, suggesting the presence of a dynamic compensation mechanism for the axial length development of preschoolers; however, the

rapid depletion of hypermetropia reserve may increase the risk of myopia [14, 15]. The core mechanism of amblyopia caused by hyperopia is form deprivation. During the critical period of visual development from 3 to 6 years old, the blurred retinal imaging caused by hyperopia will inhibit the synaptic pruning and functional differentiation of neurons in the macular area [16], and activate the competitive inhibition pathway in the visual cortex of the brain [17], which will eventually lead to the developmental delay of monocular or binocular vision. Astigmatism aggravates imaging distortion through “refractive retinal mismatch”. When the astigmatism degree is greater than 2.00D, children’s visual system cannot compensate and contrast sensitivity decreases, further increasing the risk of amblyopia [18]. Additionally, cases with astigmatism were mostly mild to moderate in severity, and our study identified that with-the-rule astigmatism accounted for 66.67% of all astigmatic cases, which is the dominant astigmatic axis type in preschool children with low vision in our cohort. This aligns with the CYL-retina mismatch hypothesis put forward by Fernandes et al.: Astigmatism causes image distortion, and inconsistent directions of visual signals received by the macular region of both eyes can trigger competitive suppression [19]. For with-the-rule astigmatism, the main refractive meridian is vertical, which leads to obvious blurring of horizontal visual signal imaging. In the critical period of preschool visual development, such directional imaging distortion impairs the normal development of visual resolution and fusion function, and when combined with hyperopia, the superimposed effect of double refractive errors further aggravates retinal imaging blur, significantly increasing the risk of amblyopia. Especially when astigmatic axes are asymmetric between the two eyes, it is more difficult for the brain to fuse blurred images and forces it to choose to suppress monocular signals [19]. Meanwhile, astigmatic AMB was found to be often complicated by hyperopic anisometropia in our study, which further confirms the superimposed damage effect of compound refractive errors on visual development. Despite the relatively low proportion of anisometric AMB, binocular SE differences >2.00 D were common in our cohort. This observation echoes Sabel BA’s theory of “binocular rivalry inhibition theory”: When the diopter difference between eyes exceeds the central fusion ability, the dominant

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Table 7. Diagnostic efficacy of the joint model for AMB

Project	AUC	95% CI	Sensitivity (%)	Specificity (%)	HL χ^2 (P)	P
Joint model	0.692	0.614-0.771	68.06	66.67	6.25 (0.615)	<0.001
Training set	0.664	0.567-0.761	74.00	56.58	4.89 (0.769)	0.002
Validation set	0.761	0.631-0.891	72.73	75.00	5.12 (0.744)	0.001

Note: AUC, Area under curve; CI, Confidence interval.

eye dominates, while the non-dominant eye gradually develops AMB due to long-term inhibition [20].

Further regression analysis indicated that refractive status were directly related to the occurrence of AMB. It is speculated that high hyperopia is caused by two mechanisms. On the one hand, it directly leads to blurred imaging in the macular area [21, 22]; on the other hand, it triggers excessive accommodative convergence, exacerbating the tendency of latent strabismus, and further disrupting the binocular visual balance [23, 24]. The elevation in CYL also signified a heightened AMB risk, mainly due to the nonlinear positive correlation between the astigmatism-induced degree of image distortion and astigmatic power. When astigmatism is greater than 2.00 D, the retinal disparity exceeds the compensatory ability of the children's visual system, leading to a significant decrease in contrast sensitivity and inhibiting the signal input of the non-dominant eye [18, 25]. Besides, the astigmatism axis distribution (with-the-rule/against-the-rule) may indirectly aggravate AMB through the accommodation-convergence synkinetic mechanism [26]. Furthermore, anisometropia has been shown to destroy the binocular competitive equilibrium through spatial frequency mismatch, with the dominant eye occupying more visual cortex resources and the non-dominant eye gradually shrinking due to long-term deprivation [27, 28]. This finding lends support to our observations. By univariate analysis, the risk of amblyopia was higher in children aged 4-5 years and lower in children aged 6 years, which may be related to the characteristics of visual development in this age group: the critical period of visual development is 4-5 years old, the ability of refractive accommodation is not stable, and the demand for near vision is increased, which easily induces amblyopia due to form deprivation. At the age of 6 years, visual development gradually matures, and some children may have received early intervention to reduce the risk. By multivariate analysis, after adjusting for confounding

factors such as refractive status and near eye time, the independent effect of age disappeared, suggesting that the effect of age on amblyopia may be achieved through these mediating variables [35801739, 32518399]. Finally, according to the above factors, we established an AMB risk assessment model, which exhibited a good evaluation effect for AMB. In the future, this model can be used in clinical practice to prioritize the referral of high-risk children, thereby reducing the risk of AMB.

Notably, parental myopia and time spent on close-range eye use were found to be independent factors influencing AMB in this study, which is consistent with the conclusions of previous reports [29, 30]. Since the relationship between the above factors and AMB has been verified many times, this article will not be repeated.

Nonetheless, single-institution sampling may introduce geographical selectivity bias. Furthermore, the retrospective design limited the data collection. This study was unable to analyze key indices such as the accommodative function (e.g., accommodation amplitude, AC/A value), and ocular deviation (angle of deviation), which may have underestimated the effect of binocular visual dysfunction on AMB. Moreover, the lack of follow-up data to validate the long-term predictive efficacy of the model, as well as the inability to track the dynamic effects of environmental interventions on refractive status and AMB, are issues that need to be addressed. In the future, multi-center prospective studies should include genetic and neuroimaging indicators and extend the follow-up time to verify the long-term predictive performance of the model. At the same time, the accommodative function, eye position, and other indicators were added to improve the amblyopia risk assessment system.

Conclusion

This study systematically revealed the distribution characteristics of refractive status in pre-

schoolers with low vision and the key patterns of AMB, confirming that parental myopia, time spent on close-range eye use, and refractive status were independent risk factors for AMB. The risk prediction model constructed provides an efficient tool for early clinical screening. In the future, multi-center prospective studies integrating genetic, environmental, and neuro-imaging data should be conducted to further optimize the AMB prevention and control system.

Disclosure of conflict of interest

None.

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