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Increasing myopic refraction reduces random dot stereopsis in Chinese myopic patients: a cross-sectional study

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Abstract

Objective To investigate the effects of myopic spherical equivalent (SE) on random dot stereopsis and influencing factors in Chinese adults with myopia.

Methods A cross-sectional design was employed, and 988 Chinese myopic individuals (520 [52.6%] females) aged 18.0–48.7 years were recruited from the People's Hospital of Guangxi. The participants underwent assessments for visual acuity, myopic SE, random dot stereopsis at 0.8 m (RDS0.8) and at 1.5 m (RDS1.5) and binocular function parameters (such as perceptual eye position (PEP), fixational eye movement, and the signal–noise ratio (SNR)). The data were analysed via Pearson or Spearman correlations and multivariate logistic regression.

Results Among the 988 participants, only 53 (5.4%) presented with abnormal RDS0.8, and 834 (84.4%) presented with abnormal RDS1.5. A significant association was found between SE and the prevalence of abnormal RDS1.5 (OR: 1.14, 95% CI: 1.03–1.26; $P=0.014$) after adjusting for covariates. High myopia was more strongly associated with abnormal RDS1.5 than mild myopia was in the unadjusted model (OR: 1.85, 95% CI: 1.03–3.26; $P=0.037$). Subgroup analyses revealed that the associations between SE and abnormal RDS1.5 were stronger among females, individuals aged > 25 years, those with normal fixational eye movement, and those with abnormal SNRs. Only vertical PEP (target 1°) was significantly associated with myopic group and abnormal RDS0.8, whereas vertical PEP (target 3°), horizontal PEP (target 1°), and vertical PEP (target 1°) were significantly associated with abnormal RDS1.5.

Conclusions Myopic SE was associated with the prevalence of abnormal random dot stereopsis at 1.5 m in myopic patients, indicating that increasing myopic SE may impair distance random dot stereopsis in this population.

Clinical trial number Not applicable.

Keywords Myopia, Stereopsis, Perceptual eye position, Chinese, Cross-sectional study

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Introduction

Myopia is a significant global health concern that is particularly prevalent in East Asia [1]. This refractive error not only impairs distant vision but also affects complex visual functions such as stereopsis [2]. Stereopsis, a fundamental process for 3D perception, involves intricate neural mechanisms from generating binocular disparity to constructing depth perception [3]. Impairments in stereopsis significantly impact daily activities, such as distance estimation and hand–eye coordination [4].

Although the effects of myopia on basic visual functions such as acuity are well documented, its impact on random dot stereopsis is less understood. A previous study revealed that, compared with emmetropes, myopes presented decreased stereopsis [5]. Among adults, stereopsis was significantly poorer in the high myopia group than in the moderate-to-low myopia group [6, 7]. In contrast, one study suggested that the severity of myopia does not affect stereoacuity in school-aged children [8]. However, some studies have shown that myopic eyes exhibit reduced efficiency in processing blurred information under monocular conditions. This deficiency improves under binocular conditions through binocular central summation [9, 10]. Additionally, under specific conditions, such as low spatial frequencies and high motion speeds, individuals with higher degrees of myopia tend to have lower motion detection thresholds in certain visual field regions, such as the nasal and superior fields. These findings indicate that myopia may partially affect peripheral motion perception [11, 12]. The ability to utilize stereoscopic depth information relies on the efficiency of processing binocular retinal images; a decline in this efficiency can affect stereopsis thresholds. A previous study revealed that myopic patients experience decreased stereoscopic vision function at specific spatial and temporal frequencies because of the weakened processing capabilities of binocular images at these frequencies, making it more difficult to judge depth accurately [13]. Collectively, these studies suggest a potential link between myopia and impaired stereopsis. However, owing to limitations such as small sample sizes and heterogeneous assessment methods, the relationship between myopia and stereopsis remains unclear.

Therefore, the present study was designed to examine the effects of the spherical equivalent on random dot stereopsis in Chinese adults with myopia. Furthermore, the effects of visual function parameters (such as division, fusion, perceptual eye position, fixational eye movements, and binocular balance points) on this relationship were analysed. Employing a robust cross-sectional methodology, we wanted to understand whether there was an association between myopia and random dot stereopsis, offering insights that may guide future therapeutic and clinical strategies to preserve and enhance binocular vision in myopic individuals.

Materials and methods

Study design and study participants

This cross-sectional study enrolled 988 Chinese adults with myopia aged between 18.0 and 48.7 years at the Optometry Clinic of People's Hospital of Guangxi from March 1 to September 30, 2022. The inclusion criteria were as follows: (1) a myopic spherical equivalent (SE) of at least 0.50 diopters (D), with astigmatism less than 2.00 D and anisometropia less than 2.00 D [14–16]; and (2) participants aged 18 years or older with a best-corrected visual acuity (BCVA) of 0.1 LogMAR or better (equivalent to 20/25 or better). The exclusion criteria were as follows: (1) inability to cooperate with the examination process; (2) a history of eye surgery; (3) the presence of binocular alignment issues or motor dysfunction, such as strabismus or nystagmus; (4) ocular diseases other than myopia; and (5) a history of systemic diseases such as heart, liver, or kidney disorders or mental health issues.

Measurement

The participants underwent assessments for visual acuity, myopic refraction, and visual function.

Measurement of visual acuity and refraction

Visual acuity was assessed monocularly by a skilled optometrist (XX) via an E-letter standard logarithmic visual acuity chart (SJ-LED-01, Guangzhou Shijia Medical Corporation, Guangzhou, China) at a 5-meter distance. The myopic spherical equivalent (SE) was determined through subjective refraction, and best-corrected visual acuity (BCVA) was recorded via the LogMAR scale. Anisometropia was defined as an interocular spherical equivalent difference of 1.00 D or more [15].

Measurement of binocular visual function

The study employed a battery of tests by ophthalmologists (YL, LL, EL, MK, and QC) to evaluate binocular visual function (Fig. 1), including tasks such as division, fusion, perceptual eye position (PEP) [17, 18], fixational eye movement, binocular balance point assessment by the signal–noise ratio (SNR) [19], and stereopsis measured via random dot stereograms at near (0.8 m from the screen, RDS0.8) and distance (1.5 m from the screen, RDS1.5) [17, 20], developed by the National Engineering Research Center for Healthcare Devices. The stimuli were generated via MATLAB and displayed on a high-resolution polarized monitor (LGD2343P, 1980 × 1080 pixels and 120 Hz refresh rate). All tests were conducted in a consistent lighting room with refractive correction provided by spectacles. All participants underwent the tests by a skilled operator, and each assessment was

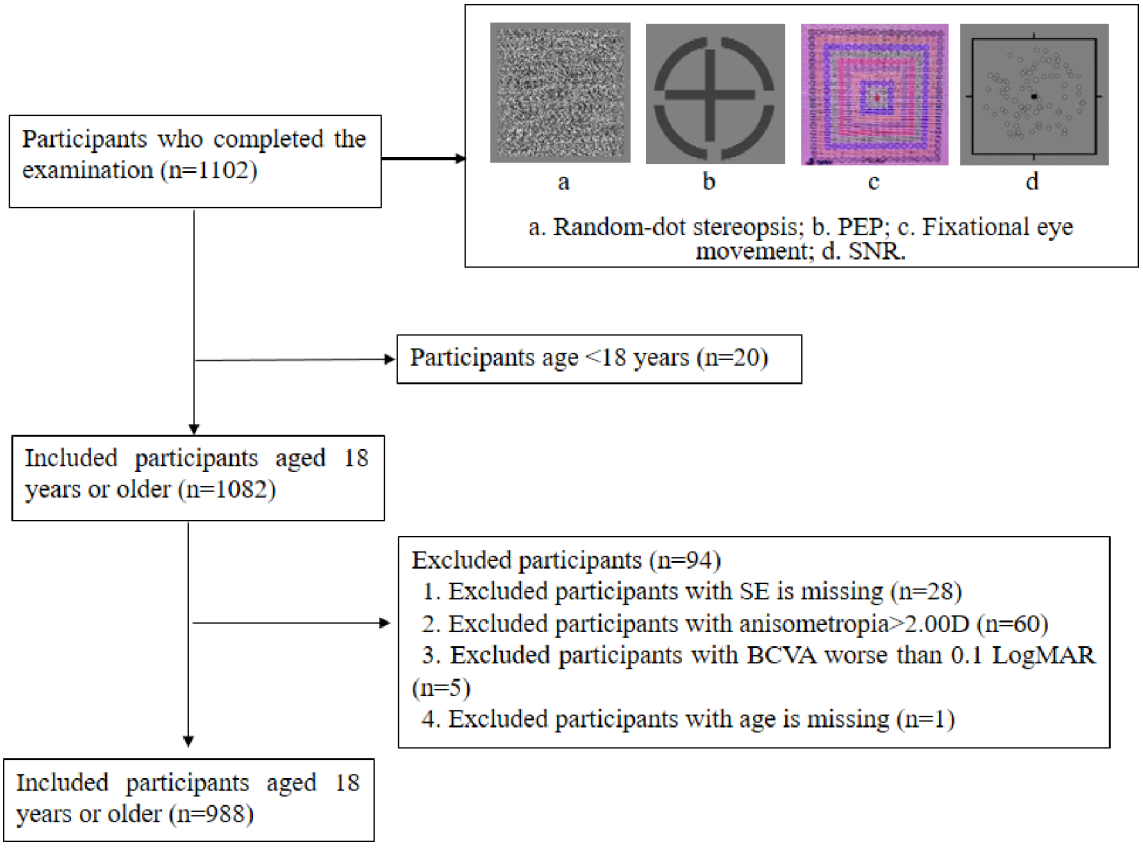

Fig. 1 Flow chart of this study. PEP: perceptual eye position; SNR: signal–noise ratio

repeated at least three times to ensure accuracy by calculating the average data. All examinations were performed with best-corrected visual acuity for all participants.

Measurement of division and fusion

The participants were positioned at a distance of 0.8 m from the screen, with their eyes aligned with the screen's height, and were instructed to maintain a stable head and body position while viewing the images. The participants looked at the two vertical lines on the screen via 3D polarized glasses. The examiner gradually increased the distance between the two vertical lines until the participants could not merge the two lines into one line (negative values represent division). The two lines were then moved in the opposite direction until the participants could not merge the two lines into one line again (positive values represent fusion).

Measurement of the PEP

The PEP test was used to assess fixational disparity and binocular visual function. It was assessed via the cross-into-circle test, in which a cross was presented to the left eye and a circle was presented to the right eye. The midpoint of the monitor was positioned 80 cm away and at the same level as the participants' eyes, with an average luminance of 80 cd/m^2 in white, decreasing to 50 cd/m^2 with the use of 3D polarized glasses, and 30 cd/m^2 in black, decreasing to 3 cd/m^2 with 3D polarized glasses. The visual stimulus template measured 51 × 29 cm in physical size and subtended a visual angle of 38° × 18°. The circle had dimensions of 0.4 × 0.4°, whereas the cross measured 0.33 × 0.33° (1° fixation test-object). The participants utilized a computer mouse to position the cross at the perceived center of the circle and were subsequently directed to click the mouse. The PEP tests were conducted according to methods reported in previous studies [15, 17, 18].

Measurement of fixational eye movement

Fixational eye movement examinations were conducted with a Tobii Eye Tracker 5 (Tobii Company, Sweden), operating at a sampling rate of 133 Hz. The average binocular accuracy of the eye tracker ranged from 0.5 to 1 degree from the visual angle. This noninvasive device allowed unrestricted head movements during testing. All assessments were efficiently completed within minutes in a controlled testing environment characterized by quiet and uniform illumination. The participants were positioned at a distance of 0.8 m from the screen, with their eyes aligned with the screen's height, and were instructed

to maintain a stable head and body position while viewing the images. Prior to each examination, a three-point calibration was conducted to ensure the accuracy and precision of gaze tracking. A circular target with a diameter of 10 degrees was presented above the foveal view in a series of nine repetitions per trial. Each target appeared for 2 s with a 0.5-second interval. The eye tracker followed the targets within a 1-degree peripheral visual field, moving at a velocity threshold of 1 degree per second. Relative deviation values in the horizontal and vertical directions from the circular target were recorded and averaged [21].

Measurement of the binocular balance point using the SNR

The participant utilized 3D polarized glasses to view stimuli on a screen, consisting of dichoptically presented signal and noise dots within a frame. Initially, the right eye viewed the signal, and the left eye viewed the noise. The signal dots moved uniformly in all directions, and the noise dots moved randomly. This arrangement was subsequently reversed. The participants had to identify the direction of the signal movement. The noise-to-signal dot ratio was adjusted until interference from the opposite eye's noise made the signal's direction indiscernible, establishing the binocular balance point. The signal–noise ratio was adjusted through eight levels, starting with 100% signal dots at level 1 and decreasing by 10% per level down to 20% at level 8, with a corresponding increase in noise dots. This test measures how well the signal eye resists noise interference, reflecting binocular balance ability. Each level involved three trials; passing required correct identification, which allowed progression to the next level. The binocular signal–noise ratios were recorded as balance point values [22].

Measurement of random dot stereopsis

A random dot distribution stereogram with a luminance of 44 cd/m^2 on a gray background of 125 was displayed on a 3D monitor. Within a 5° × 5° square area, 1250 random dots on a gray background of 250 were arranged. The participants observed a central optotype, an E-target measuring 3° × 3°, positioned within the central region of the random dot distribution map. The surrounding random dots served as a reference for relative nonparallax. The participant utilized 3D polarized glasses and was directed to identify the orientation of the protruding E-target aperture displayed on the screen by selecting the corresponding arrow icon via mouse or keyboard input. Various levels of disparity, including 400", 300", 200", and 100", were utilized. Initially, the participant observed a protruding E-target with a size of 400" and was tasked with identifying the aperture orientation twice. Successful identification on both occasions resulted in the presentation of a smaller protruding E-target measuring 300", with subsequent reductions in size continuing until reaching 100". If the participant provided an incorrect response, the test would revert to the previous higher level of discrepancy. The outcome was documented, with assessment distances categorized as 0.8 m (RDS0.8) and 1.5 m (RDS1.5). The principle and detection process of the random dot stereopsis test was described in a previous study [23], and the results showed that the random dot stereopsis test results are consistent with the Titmus test results (*Kappa* = 0.493).

Definition

Myopia was divided into three groups according to SE: mild myopia (SE >-3.00 D and ≤-0.50 D), moderate myopia (SE > -6.00 D and ≤ -3.00 D) and high myopia (SE ≤ -6.00 D). Various levels of random dot stereopsis at 0.8 m (RDS0.8) and 1.5 m (RDS1.5), including 400", 300", 200", and 100". Normal stereopsis was defined as 100", and abnormal stereopsis was defined as > 100" (400", 300", and 200"). The SNRs of the right eye or left eye were recorded at levels 1 to 8. A normal SNR is defined as the same SNR level for the left and right eyes. An abnormal SNR was defined as the difference between the SNR level of the right eye and the SNR level of the left eye (e.g., an SNR level of 2 for the right eye and an SNR level of 3 for the left eye). Fixational eye movement results are divided into four levels: stable, normal, shaking, and running. Normal fixational eye movements were defined as stable and normal. Abnormal fixational eye movements were defined as shaking and running.

Statistical analysis

Statistical analyses were conducted via R, a popular software package (version 4.3.1, The R Foundation, released on 2024-05-06; http://www.R-project.org). The distrib ution of measurement data was assessed through the Shapiro–Wilk test, with the results reported as the means ± SDs for normally distributed data or medians (P_{25}, P_{75}) for nonnormally distributed data. Correlation tests were performed with Pearson's method for normally distributed data and Spearman's test for nonnormally distributed data.

To investigate the relationship between the spherical equivalent (SE) and the prevalence of abnormal random dot stereopsis, a multivariate logistic regression model was employed. Model 1 included age and sex as covariates; Model 2 added anisometropia, astigmatism, and BCVA to Model 1 [20]. In addition, the stability of the study results was verified via subgroup analyses. Significance was set at $P < 0.05$.

Results

Demographic and clinical characteristics of the participants

From March 1 to September 30, 2022, a total of 1102 Chinese adults with myopia were recruited, and 988 patients, aged 18.0 to 48.7 years, completed the test at the Optometry Clinic of People's Hospital of Guangxi. The study flowchart is depicted in Fig. 1. Table 1 shows significant differences in sex, age, degree of anisometropia, SE, astigmatism, vertical PEP (target 1°), SNR, and RDS1.5 among the mild, moderate, and high myopia groups (all $P < 0.05$).

Association between myopic SE and abnormal random dot stereopsis

Among the 988 participants, only 53 (5.4%) presented with abnormal RDS0.8, and 834 (84.4%) presented with abnormal RDS1.5 (Table 1). Table 2 displays the associations between these factors and the risk of abnormal RDS0.8, with univariate analysis revealing significant associations with the degree of anisometropia and vertical PEP (target 1°) (both $P < 0.05$). However, there were no significant correlations between myopia and RDS0.8 (Table 2).

Participants with abnormal RDS1.5 had greater SEs than those with normal RDS1.5 ($P < 0.001$; Fig. 2). SE was significantly associated with abnormal RDS1.5 based on correlation analysis (Table 3; Fig. 3). Therefore, multivariate logistic regression analysis and subgroup analyses were performed using RDS1.5 data. However, abnormal RDS1.5 was not significantly correlated with sex, age, degree of anisometropia, division, fusion, fixational eye movement or the SNR (Table 3; Fig. 3). After adjustment for influential confounders in Model 2, the associations between SE and abnormal RDS1.5 remained significant (OR = 1.14, 95% CI: 1.03–1.26, $P = 0.014$; Table 4). Furthermore, high myopia was more strongly associated with abnormal RDS1.5 than mild myopia was (OR = 1.85, 95% CI: 1.03–3.26, $P = 0.037$; Table 4) according to the unadjusted model, whereas adjustment for covariates revealed that high myopia was not associated with

Table 1 Characteristics of the participants in the myopia group

Variables	Total ($n = 988$)	Mild myopia ($n = 119$)	Moderate myopia ($n = 531$)	High myopia ($n = 338$)	*P* value
Sex[a]					<0.001
Male	468 (47.4%)	83 (69.7%)	234 (44.1%)	151 (44.7%)	
Female	520 (52.6%)	36 (30.3%)	297 (55.9%)	187 (55.3%)	
Age[b] (year)	25.4 ± 6.18	23.6 ± 5.86	26.2 ± 6.37	24.7 ± 5.79	<0.001
Anisometropia[b] (D)	0.51 ± 0.46	0.60 ± 0.56	0.48 ± 0.44	0.54 ± 0.45	0.018
SE[b] (D)	5.18 ± 1.97	2.14 ± 0.58	4.48 ± 0.85	7.34 ± 1.18	<0.001
Astigmatism[b] (D)	0.92 ± 0.70	0.60 ± 0.52	0.82 ± 0.65	1.18 ± 0.76	< 0.001
BCVA[b] (LogMAR)	-0.01 ± 0.03	0.00 ± 0.02	0.00 ± 0.03	-0.01 ± 0.03	0.289
Division[b]	-7.56 ± 5.91	-6.98 ± 4.90	-7.43 ± 5.00	-7.98 ± 7.40	0.227
Fusion[b]	4.02 ± 4.89	3.77 ± 3.61	4.21 ± 5.21	3.79 ± 4.76	0.411
PEP_Hori_Big[b]	22.6 ± 43.2	23.1 ± 39.6	20.9 ± 41.3	25.0 ± 47.1	0.402
PEP_Vect_Big[b]	5.51 ± 4.91	4.93 ± 4.09	5.41 ± 4.45	5.87 ± 5.76	0.161
PEP_Hori_Small[b]	28.9 ± 55.3	25.9 ± 39.2	26.8 ± 54.0	33.2 ± 61.7	0.209
PEP_Vect_Small[b]	3.87 ± 5.57	3.51 ± 3.63	3.57 ± 5.04	4.48 ± 6.77	0.049
Fixational eye movement[a]					0.148
Normal	694 (70.3%)	82 (68.9%)	387 (72.9%)	225 (66.8%)	
Abnormal	293 (29.7%)	37 (31.1%)	144 (27.1%)	112 (33.2%)	
SNR[a]					0.002
Normal	258 (37.3%)	46 (51.7%)	140 (37.9%)	72 (30.9%)	
Abnormal	433 (62.7%)	43 (48.3%)	229 (62.1%)	161 (69.1%)	
RDS0.8[a]					0.443
Normal	935(94.6%)	110(92.4%)	506(95.3%)	319(94.4%)	
Abnormal	53(5.4%)	9(7.6%)	25(4.7%)	19(5.6%)	
RDS1.5[a]					0.015
Normal	154 (15.6%)	22 (18.5%)	95 (17.9%)	37 (10.9%)	
Abnormal	834 (84.4%)	97 (81.5%)	436 (82.1%)	301 (89.1%)	

SE: all myopic values were reported as absolute values; BCVA: best corrected visual acuity; LogMAR: logarithm of the minimum angle of resolution; PEP_Hori_Big: horizontal PEP (target 3°); PEP_Vect_Big: vertical PEP (target 3°); PEP_Hori_Small: horizontal PEP (target 1°); PEP_Vect_Small: vertical PEP (target 1°); SNR: signal–noise ratio; RDS0.8: stereopsis measured via random dot stereograms at 0.8 m from the screen; RDS1.5: stereopsis measured via random dot stereograms at 1.5 m from the screen; mild myopia: SE >-3.00 D and ≤-0.50 D; moderate myopia: SE >-6.00 D and ≤-3.00 D; high myopia: SE ≤-6.00 D

[a] Chi-square test was used

[b] One-way ANOVA was used

Table 2 Associations between covariates and abnormal RDS0.8 risk via univariate logistic regression analysis

Variables	Normal (*n* = 935)	Abnormal (*n* = 53)	OR[95% CI]	*P* value
Sex				0.214
Male	438 (46.8%)	30 (56.6%)	Ref.	
Female	497 (53.2%)	23 (43.4%)	0.68 [0.38;1.18]	
Age (year)	25.4 (6.19)	24.9 (6.19)	0.99 [0.94;1.03]	0.553
Anisometropia (D)	0.51 (0.46)	0.67 (0.46)	1.94 [1.15;3.28]	0.015
SE (D)	5.17 (1.97)	5.28 (2.02)	1.03 [0.89;1.18]	0.709
BCVA (LogMAR)	-0.01 (0.03)	0.00 (0.02)	6.69 [0.00;337234]	0.629
Myopia_group				0.443
Mild myopia	110 (11.8%)	9 (17.0%)	Ref.	
Moderate myopia	506 (54.1%)	25 (47.2%)	0.60 [0.28;1.40]	
High myopia	319 (34.1%)	19 (35.8%)	0.72 [0.32;1.74]	
Division	-7.61 (5.93)	-6.65 (5.62)	1.03 [0.97;1.10]	0.264
Fusion	4.04 (4.88)	3.50 (5.08)	0.98 [0.91;1.04]	0.480
PEP_Hori_Big	21.9 (40.7)	34.2 (74.7)	1.00 [1.00;1.01]	0.244
PEP_Vect_Big	5.41 (4.57)	7.27 (8.99)	1.05 [1.01;1.10]	0.148
PEP_Hori_Small	28.8 (55.8)	30.7 (45.2)	1.00 [1.00;1.01]	0.776
PEP_Vect_Small	3.73 (5.36)	6.52 (8.30)	1.05 [1.02;1.08]	0.023
Fixational eye movement				0.490
Normal	654 (70.0%)	40 (75.5%)	Ref.	
Abnormal	280 (30.0%)	13 (24.5%)	0.77 [0.39;1.42]	
SNR				0.159
Normal	250 (38.0%)	8 (24.2%)	Ref.	
Abnormal	408 (62.0%)	25 (75.8%)	1.89 [0.87;4.58]	

SE: all myopic values were reported as absolute values; BCVA: best corrected visual acuity; LogMAR: logarithm of the minimum angle of resolution; mild myopia: SE >-3.00 D and ≤-0.50 D; moderate myopia: SE >-6.00 D and ≤-3.00 D; high myopia: SE ≤-6.00 D; PEP_Hori_Big: horizontal PEP (target 3°); PEP_Vect_Big: vertical PEP (target 3°); PEP_Hori_Small: horizontal PEP (target 1°); PEP_Vect_Small: vertical PEP (target 1°); SNR: signal-to-noise ratio; RDS0.8: stereopsis measured via random dot stereograms at 0.8 m from the screen

abnormal RDS1.5 compared with mild myopia ($P > 0.05$; Table 4). Subgroup analyses revealed that the associations between SE and abnormal RDS1.5 were stronger among females (OR = 1.19, 95% CI: 1.02–1.39, $P = 0.027$; Fig. 4), individuals aged > 25 years (OR = 1.23, 95% CI: 1.06–1.44, $P = 0.008$; Fig. 4), those with normal fixational eye movement, and those with abnormal SNRs.

Associations between visual functions and abnormal random Dot stereopsis

Fixational eye movement was not significantly different among the study groups (Table 1) and was not associated with abnormal RDS0.8 (Table 2; Fig. 3) or abnormal RDS1.5 in the correlation analysis (Table 3; Fig. 3). However, the associations between SE and abnormal RDS1.5 were stronger in individuals with normal fixational eye movement (OR = 1.21; 95% CI: 1.07–1.37, $P = 0.002$; Fig. 4).

The SNR was significantly different among the study groups (Table 1), but there was no association with abnormal RDS0.8 (Table 2; Fig. 3) or abnormal RDS1.5 in the correlation analysis (Table 3; Fig. 3). However, in the abnormal SNR group, SE was more strongly correlated with abnormal RDS1.5 (OR = 1.28, 95% CI: 1.09–1.52, $P = 0.004$; Fig. 4).

In terms of perceptual eye position, only the vertical PEP (target 1°) significantly differed among the study groups (Table 1). Only the vertical PEP (target 1°) was significantly associated with an abnormal RDS0.8 in the correlation analysis ($P < 0.05$; Table 2; Fig. 3). Vertical PEP (target 3°), horizontal PEP (target 1°), and vertical PEP (target 1°) were significantly associated with abnormal RDS1.5 in the correlation analysis (all $P < 0.05$; Table 3; Fig. 3).

Discussions

In this study, we investigated how spherical equivalent relates to random dot stereopsis abnormalities at different distances in Chinese myopic patients. We found a greater prevalence of random dot stereopsis abnormalities in patients with more severe myopia, especially those with high myopia. These findings suggest that myopia may affect random dot stereopsis, resulting in differences in visual function impairment based on myopia severity. Individuals with anisometropia often have stereopsis problems [17]. The prevalence of abnormal stereopsis in the general population varies from 3 to 70% [5, 15, 17, 24, 25]. This report of the prevalence of abnormal RDS0.8 (5.36%) was consistent with previous studies among the myopic population [5]. However, the rate of anomalies

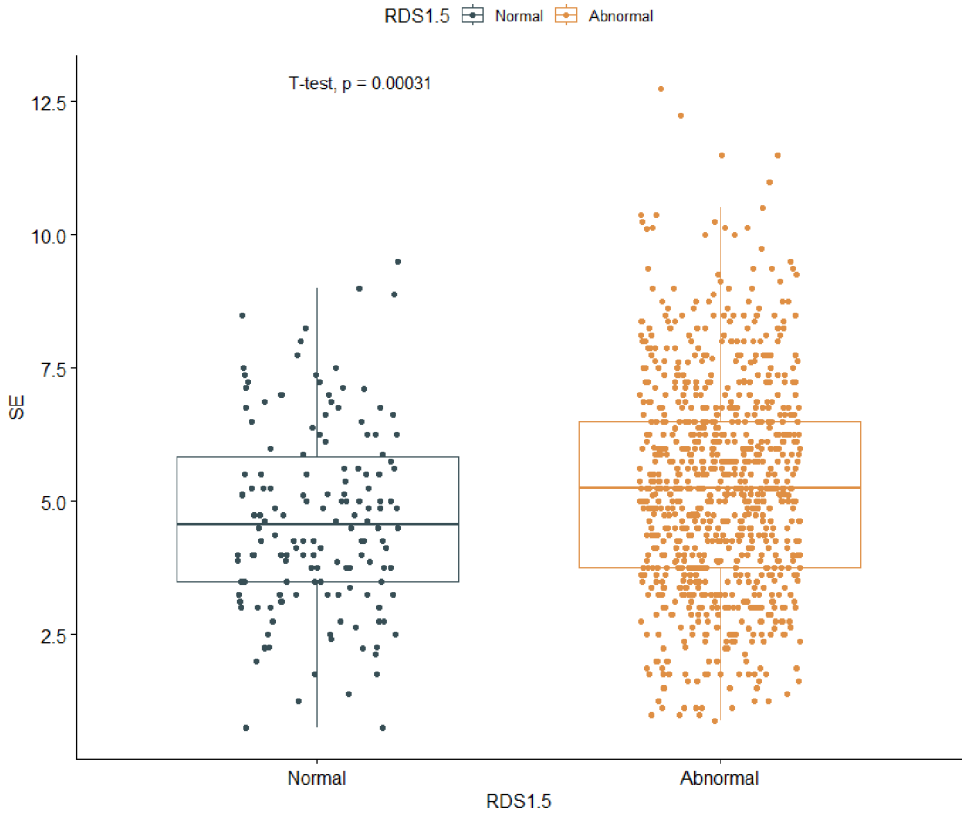

Fig. 2 Boxplot and scatter plot of myopic SE against abnormal RDS1.5. The horizontal axis represents stereopsis measured by random dot stereograms at 1.5 m, whereas the vertical axis represents myopic spherical equivalent. SE: spherical equivalent; RDS1.5: stereopsis measured via random dot stereograms at 1.5 m from the screen

was much higher in RDS1.5 (84.4%). Near and distance stereopsis represent different aspects of binocular vision; near vision enhances depth perception through increased binocular convergence, whereas distant vision, with parallel eyes, often results in reduced stereopsis [26]. Previous studies have focused on near stereopsis and overlooked the importance of distance stereopsis [17, 27–29]. Patients with high myopia exhibited significant abnormalities in random dot stereopsis at 1.5 m, followed by moderate and mild myopia in this study. Patients with myopia may have difficulty with relative static stereopsis due to imbalanced binocular competition and mild interocular suppression [30]. This may be related to changes in eye structure, such as elongation of the axial length, which can stretch the retina, impair photoreceptor function, and affect stereopsis [31].

Compared with emmetropes, individuals with myopia presented weaker stereopsis and greater binocular imbalance at higher spatial and lower temporal frequencies [13]. This finding indicates that depth perception in myopia is influenced by alterations in binocular image processing, making it more difficult to judge depth accurately under certain viewing conditions. Our results are in agreement with the results of that analysis. One possible explanation for this phenomenon is abnormalities in magnocellular pathways. The signals of the magnocellular pathway are located primarily within the peripheral retina, where they play a significant role in depth perception and motion detection [32, 33]. Therefore, structural and functional alterations associated with ocular elongation in myopia may impair magnocellular processing, resulting in decreased stereopsis.

Previous studies have examined the link between myopia and stereopsis but have not considered the influence of sex and age. This study investigated the relationship between myopia and random dot stereopsis abnormalities, with a focus on sex and age. A significant positive correlation between myopia and stereopsis abnormalities was detected in females compared with males. Significant differences in visual acuity and refractive status were observed in female myopic patients during different menstrual cycles, possibly due to the role of estrogen in regulating eye components [34]. Changes in female hormone levels can also cause temporary visual blurriness by affecting tear film stability [34]. Moreover, women are more likely to develop high myopia than men are, possibly because men spend more time outdoors, which can slow the progression of myopia [35, 36]. This study also revealed more women with moderate to high myopia, suggesting that they may be more susceptible to

Table 3 Associations between covariates and abnormal RDS1.5 risk via univariate logistic regression analysis

Variables	Normal *N* = 154	Abnormal *N* = 834	OR[95% CI]	*P* value
Sex				0.533
Male	77 (50.0%)	391 (46.9%)	Ref.	
Female	77 (50.0%)	443 (53.1%)	1.13 [0.80;1.60]	
Age (year)	25.8 ± 6.07	25.3 ± 6.20	0.99 [0.96;1.01]	0.308
Anisometropia (D)	0.52 ± 0.46	0.51 ± 0.46	0.99 [0.68;1.44]	0.959
SE (D)	4.69 ± 1.75	5.27 ± 2.00	1.17 [1.07;1.28]	<0.001
Astigmatism (D)	0.74 ± 0.52	0.95 ± 0.73	1.70 [1.25;2.30]	< 0.001
BCVA (LogMAR)	-0.02 ± 0.05	0.00 ± 0.02	196,218 [1394;27610908]	0.001
Myopia group				0.015
Mild myopia	22 (14.3%)	97 (11.6%)	Ref.	
Moderate myopia	95 (61.7%)	436 (52.3%)	1.05 [0.61;1.72]	
High myopia	37 (24.0%)	301 (36.1%)	1.85 [1.02;3.27]	
Division	-7.43 ± 4.87	-7.58 ± 6.08	1.00 [0.96;1.03]	0.742
Fusion	4.13 ± 4.70	4.00 ± 4.93	0.99 [0.96;1.03]	0.765
PEP_Hori_Big	18.1 ± 35.00	23.4 ± 44.50	1.00 [1.00;1.01]	0.103
PEP_Vect_Big	4.65 ± 4.26	5.67 ± 5.00	1.06 [1.01;1.11]	0.009
PEP_Hori_Small	18.3 ± 29.80	30.8 ± 58.60	1.01 [1.00;1.01]	<0.001
PEP_Vect_Small	2.91 ± 3.96	4.05 ± 5.80	1.07 [1.01;1.13]	0.003
Fixational eye movement				0.317
Normal	114 (74.0%)	580 (69.6%)	Ref.	
Abnormal	40 (26.0%)	253 (30.4%)	1.24 [0.85;1.85]	
SNR				0.163
Normal	54 (43.2%)	204 (36.0%)	Ref.	
Abnormal	71 (56.8%)	362 (64.0%)	1.35 [0.91;2.00]	

SE: all myopic values were reported as absolute values; BCVA: best-corrected visual acuity; LogMAR: logarithm of the minimum angle of resolution; mild myopia: SE >-3.00 D and ≤-0.50 D; moderate myopia: SE >-6.00 D and ≤-3.00 D; high myopia: SE ≤-6.00 D; PEP_Hori_Big: horizontal PEP (target 3°); PEP_Vect_Big: vertical PEP (target 3°); PEP_Hori_Small: horizontal PEP (target 1°); PEP_Vect_Small: vertical PEP (target 1°); SNR: signal-to-noise ratio; RDS1.5: stereopsis measured via random dot stereograms at 1.5 m from the screen

stereopsis abnormalities. Moreover, we discovered that age also plays a significant role in the relationship between myopia and stereopsis abnormalities. A previous study revealed that defective stereopsis is common in the elderly population (aged > 65 years). These findings indicate that an age-related decrease in ocular structure and cerebral function may worsen the impact on stereopsis [37]. However, the relatively young age of the participants in this study (25.4 ± 6.18 years) was attributable to the clinical setting, as most subjects were enrolled from a refractive surgery outpatient clinic, where many patients were young adults seeking myopia correction. Thus, further studies should expand the scope of the study population to confirm this viewpoint.

In vision science, noise can interfere with the process of transforming light into electrical signals in the retina, ultimately affecting visual perception [38, 39]. Compared with background noise, the strength of neural responses, known as the SNR, plays a significant role in this association. The perceptual template model (PTM) proposes that the brain utilizes both internal and external mechanisms to reduce noise, but too much noise can hinder this ability [40]. The SNR can be used to evaluate binocular imbalance [41]. This study revealed that the greater the severity of myopia is, the worse the stereopsis is in binocular imbalance individuals. Short-term binocular imbalance is typically a temporary physiological occurrence that does not harm visual acuity or function [42]. It should be considered pathological only if it persists and leads to amblyopia [43]. The brain selects a clearer image that may damage stereopsis during long-term binocular imbalance [44].

Previous doubts about fixational eye movements as a hindrance to visual perception have been made [45]. That is, the stronger the fixational eye movements are, the worse the visual function is [46]. However, in light of our findings, this view warrants reconsideration. We found that stable and normal fixational eye movements were linked to a stronger connection between myopia and stereopsis abnormalities. This result suggested that people need to constantly adjust eye movements (micro saccades and ocular drifts) to precisely position the retinal image and achieve stereoscopic images rather than complete stillness in both eyes [47]. Generally, eye movements are common during periods of fixation in real-life situations. Our previous study reported that healthy individuals make quick eye movements between target positions to maintain perception and spatial orientation

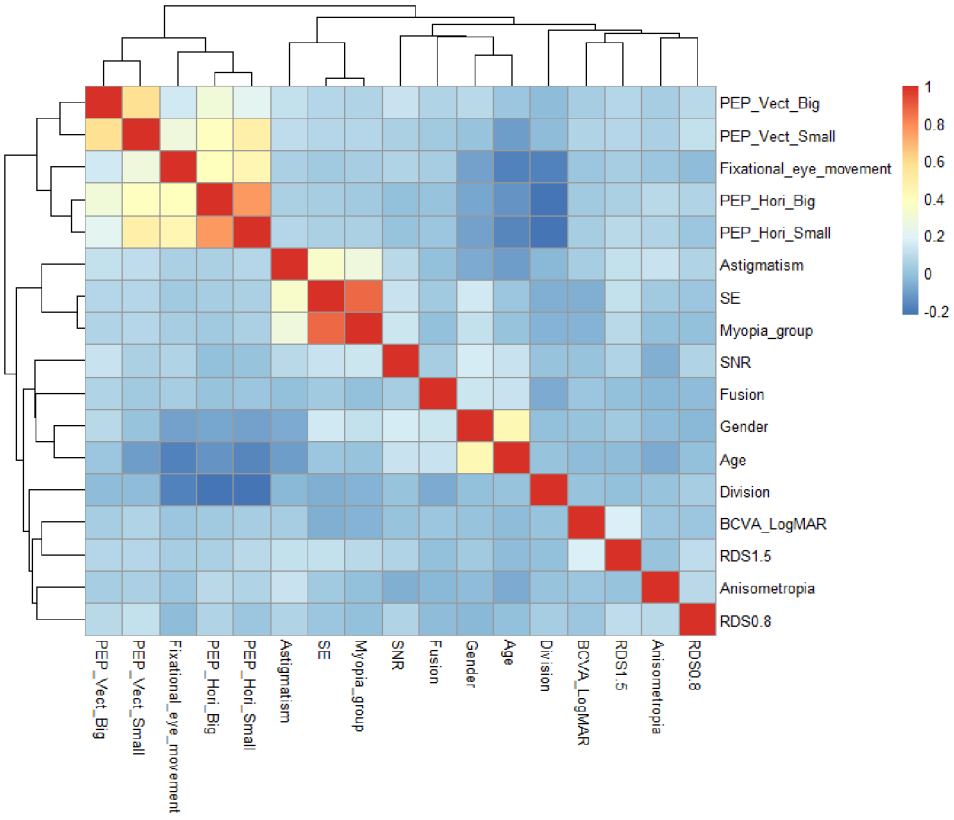

Fig. 3 Heatmap of correlations between covariates and abnormal RDS1.5. SE: all myopic values were reported as absolute values; RDS1.5: stereopsis measured via random dot stereograms at 1.5 m from the screen; RDS0.8: stereopsis measured via random dot stereograms at 0.8 m from the screen; BCVA: best-corrected visual acuity; LogMAR: logarithm of the minimum angle of resolution; PEP_Hori_Big: horizontal PEP (target 3°); PEP_Vect_Big: vertical PEP (target 3°); PEP_Hori_Small: horizontal PEP (target 1°); PEP_Vect_Small: vertical PEP (target 1°); SNR: signal–noise ratio

Table 4 Associations between myopic SE and abnormal RDS1.5 risk among myopic patients

Myopia	No	Unadjusted model		Model 1[a]		Model 2[b]	
		OR [95%CI]	*P* value	OR [95%CI]	*P* value	OR [95%CI]	*P* value
SE (Diopter)	988	1.17 [1.07;1.28]	< 0.001	1.16 [1.06;1.28]	0.002	1.14 [1.03;1.26]	0.014
Myopia group							
Mild myopia	119	1(Ref.)		1(Ref.)		1(Ref.)	
Moderate myopia	531	1.04 [0.61; 1.71]	0.878	1.04 [0.60; 1.72]	0.894	0.97 [0.56; 1.64]	0.914
High myopia	338	1.85 [1.03; 3.26]	0.037	1.79 [0.99; 3.19]	0.050	1.55 [0.83; 2.85]	0.161

SE: all myopic values are reported as absolute values; mild myopia: SE >-3.00 D and ≤-0.50 D; moderate myopia: SE >-6.00 D and ≤-3.00 D; high myopia: SE ≤-6.00 D; RDS1.5: stereopsis measured via random dot stereograms at 1.5 m from the screen

[a] Model 1 was adjusted for age and sex

[b] Model 2 was adjusted for Model 1 + anisometropia, astigmatism, and BCVA

[21]. These fixational eye movements are crucial for normal visual tasks, especially dynamic mobility vision tasks. Stereopsis involves being able to see and differentiate small differences in depth, which helps people notice subtle 3D details. Problems with this could greatly affect daily activities, such as driving, sports, hand–eye coordination tasks, and art appreciation [14, 48–50]. This study revealed a link between severe myopia and difficulties with stereopsis at a distance of 1.5 m. Consequently, it is imperative to conduct comprehensive visual function assessments for myopic patients, especially those with high myopia. The timely identification of random dot stereopsis impairments and the implementation of appropriate interventions, in addition to correcting refractive errors, are crucial. Vision function training, which capitalizes on neural plasticity, involves a series of visual training tasks to increase the ability of the brain to process binocular disparities and stereopsis in various environments. This training could facilitate improved adaptation to visual challenges in daily activities, ultimately enhancing overall quality of life.

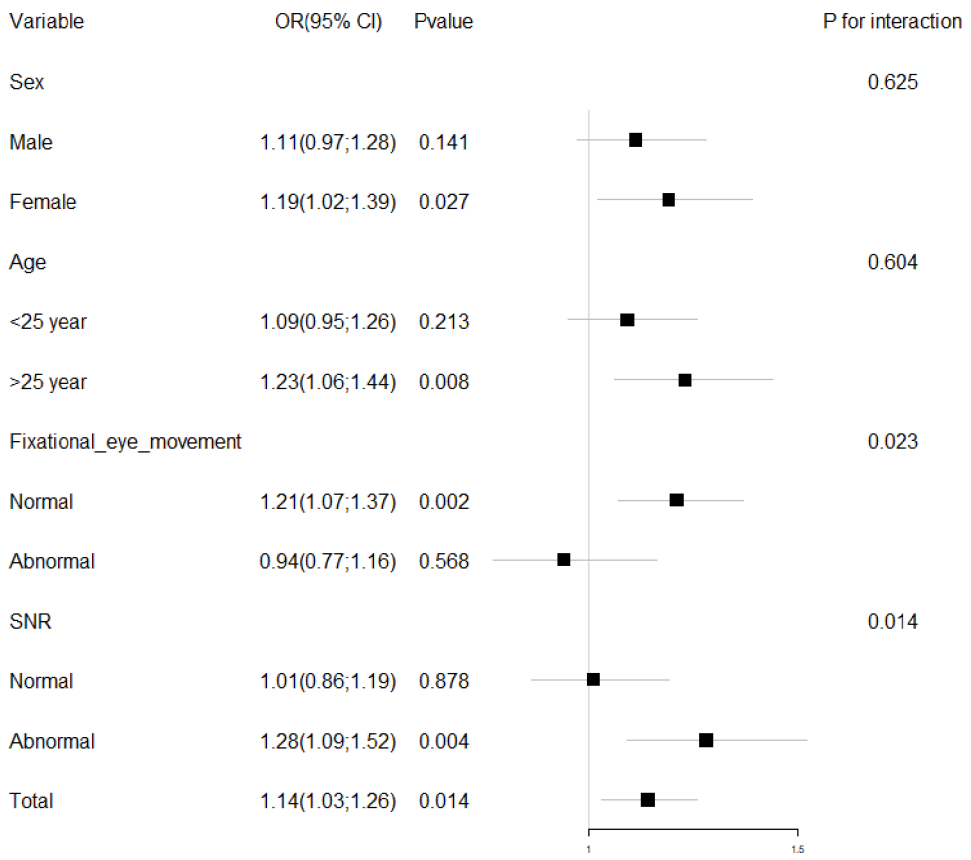

Fig. 4 Forest plot of subgroup analysis of the association between myopic SE and abnormal RDS1.5 by covariates. SE: all myopic values were reported as absolute values; SNR: signal–noise ratio; OR: odds ratio; RDS1.5: stereopsis measured via random dot stereograms at 1.5 m from the screen

Abnormal eye position and stereopsis are the main clinical manifestations of strabismus [17] and amblyopia [51]. We found the same relationship between PEP and stereopsis among myopic populations. Sensory fusion can be maintained through precise adjustments in eye positions to align the binocular images. Only then is normal stereopsis possible to achieve [52, 53]. The traditional eye position assessed by the Hirschberg and cover tests indicates apparent eye alignment. However, the PEP reflects the brain's integration of visual input via a computer-controlled perceptual examination system under dichoptic conditions. This test is more precise than the synoptophore test. Therefore, individuals with a normal apparent eye position may present PEP abnormalities [18].

This study revealed a link between SE and abnormal stereopsis in myopic patients, but the design limits conclusions about causality. In addition, the age range of the participants included in the present study was rather small. Children and the elderly population were not included in the sample. Prospective studies with larger samples are needed to further validate the association between myopia and stereopsis. This is the next step of our ongoing study, expanding the study to include children and adolescents to assess refractive status and visual function changes, as well as their impact on individual behavior. This approach can clarify the causal relationships among refractive error, stereopsis, and behavioral outcomes. Further study is also recommended to evaluate whether visual function training can enhance stereopsis in myopic individuals, particularly those with abnormal visual function.

In conclusion, this study revealed that SE affects distance random dot stereopsis in Chinese myopic patients, especially in females, those aged over 25 years, and patients with normal fixational eye movements and abnormal SNRs. These results highlight the need for tailored management strategies for myopia and offer insights for targeted clinical interventions.

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Author contributions
Conceptualization, XX and WQL; data analysis, XX; writing—original draft preparation, XX; data curation, XYY, LLL, EWL, MK, QC, JZ, LY; Investigation, YL, MK, QC; validation, EWL, MK, QC; writing-- reviewing and editing, YL, JZ, LY, WQL.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study adhered to the ethical principles outlined in the Declaration of Helsinki and received approval from the Ethics Committee of the People's Hospital of Guangxi (KY-KJT-2023-285). All participating patients provided informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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