Cardiovascular Reviews, 2026, Volume 4, Issue 2
http://ojs.bbwpublisher.com/index.php/CR
Online ISSN: 2981-8109
Print ISSN: 3083-4880

Research on the Correlation between Eye Movement Characteristics and Cognitive Impairment in Patients with Cerebral Small Vessel Disease

Qiang Zhang[1], Borui Zhang[2], Ningning Gao[3], Xiaojie Wang[4], Hong Zhang[1]*

[1]Department of Neurology, Shaanxi Provincial People's Hospital, Xi'an 710068, Shaanxi, China
[2]Department of Anesthesiology, Shaanxi Provincial People's Hospital, Xi'an 710068, Shaanxi, China
[3]Department of Ophthalmology, Shaanxi Provincial People's Hospital, Xi'an 710068, Shaanxi, China
[4]Xi'an Medical University, Xi'an 710021, Shaanxi, China

Author to whom correspondence should be addressed.

Abstract: *Objective*: To explore the eye movement characteristics of patients with cerebral small vessel disease (CSVD) and their correlation with cognitive impairment, and to validate the application value of eye-tracking technology in the early screening of CSVD-related cognitive impairment. *Methods*: A total of 81 subjects were included, with 51 in the CSVD group and 30 in the healthy control group. Cognitive assessment was conducted using the MoCA scale, and visual pairing and antisaccade tasks were detected using an AI-assisted eye-tracking system. Differences in eye movement parameters between the two groups were compared, and the correlation between eye movement indicators and cognitive scores was analyzed. *Results*: The saccade error rate in the CSVD group was significantly higher than that in the control group ($P = 0.009$). The total MoCA score, visuospatial and executive function, attention, and language function scores were significantly lower in the CSVD group than in the control group (all $P < 0.05$). The saccade error rate was significantly negatively correlated with the total MoCA score (rs = -0.382, $P = 0.0005$) and visuospatial and executive function score (rs = -0.313, $P = 0.005$). *Conclusion*: Patients with CSVD exhibit characteristic eye movement abnormalities, and the saccade error rate can serve as an objective biomarker reflecting their executive function and overall cognitive impairment. Eye-tracking technology provides a non-invasive, objective, and efficient new means for the early screening of CSVD-related cognitive impairment.

Keywords: Cerebral small vessel disease; Cognitive impairment; Eye-tracking; Antisaccade; Biomarker

Online publication: June 30, 2026

1. Introduction

With the acceleration of global population aging, the incidence of cerebral small vessel disease (CSVD)

continues to rise, leading to approximately one-fourth of ischemic strokes and 35%–67% of vascular dementia cases, imposing a heavy disease burden on families and society [1,2]. CSVD-related cognitive impairment has an insidious onset and slow progression, often manifesting as mild cognitive impairment (MCI) in the early stages. If not promptly identified and intervened upon, it can easily progress to irreversible dementia. Currently, clinical cognitive assessment still relies mainly on neuropsychological scales such as MMSE and MoCA, which have limitations such as strong subjectivity, time-consuming, significant influence by educational level and audiovisual status, and high professional requirements for the examiner, making it difficult to meet the needs of large-scale, primary-level, and early rapid screening. Eye movements directly reflect core cognitive functions such as attention, executive control, working memory, and visual processing, and their abnormalities can objectively indicate corresponding brain network damage [1]. CSVD-induced white matter hyperintensities, lacunar infarcts, microbleeds, and other lesions often disrupt the prefrontal-subcortical inhibitory control pathway, leading to abnormalities in saccade, fixation, and antisaccade eye movement behaviors. In recent years, eye-tracking (ET) technology has demonstrated good biomarker value in the screening of MCI related to Alzheimer's disease due to its non-invasive, objective, repeatable, portable, and efficient advantages [3]. However, there is still a lack of sufficient evidence-based evidence regarding the specific eye movement characteristics of CSVD-MCI, their quantitative correlation with cognitive impairment, and screening efficacy. This study systematically analyzed the differences in eye movement characteristics in patients with CSVD, clarified the correlation between key eye movement indicators and cognitive domain impairment, and validated the early screening value of eye-tracking technology, providing clinical evidence for constructing a digital screening system for CSVD-related cognitive impairment.

2. Objects and methods

2.1. Study objects

This study included 51 patients with sporadic CSVD diagnosed in the Department of Neurology at Shaanxi Provincial People's Hospital from February 2024 to December 2025 as the case group; 30 healthy individuals who underwent physical examinations during the same period were selected as the control group. The study protocol was reviewed and approved by the hospital's ethics committee, and all enrolled subjects or their family members signed informed consent forms.

Inclusion criteria: (1) Age between 50 and 80 years old; (2) Met the diagnostic criteria for sporadic CSVD in the "Expert Consensus on the Diagnosis and Treatment of Cerebral Small Vessel Disease in China 2021" [2]; (3) Had at least 6 years of education.

Exclusion criteria: (1) Had mental disorders or reading disorders; (2) Had strabismus, amblyopia, dry eye, color vision abnormalities, or other refractive diseases affecting the test results; (3) Had significant visual fatigue within 3 days before the test; (4) Had acute stroke or transient ischemic attack within the past 3 months, or CSVD caused by metabolic, toxic, infectious, or genetic factors; (5) Had intracranial or extracranial artery stenosis > 50%, a history of large-area cerebral infarction or intracranial hemorrhage; (6) Had other neurological diseases such as Alzheimer's disease, Parkinson's disease, or intracranial tumors; (7) Had severe heart, liver, kidney, or thyroid dysfunction; (8) Had a history of alcohol/drug dependence, malignant tumor, or brain surgery; (9) Were unable to cooperate with eye movement testing.

2.2. Methods

2.2.1. Collection of general and clinical data

Detailed records were kept of the subjects' gender, age, duration of education, body mass index (BMI), and clinical information such as hypertension, type 2 diabetes, hyperlipidemia, atrial fibrillation, coronary heart disease, stroke history, smoking history, and alcohol consumption history; laboratory tests were also conducted on the subjects, including blood routine, uric acid (UA), fasting blood glucose, and homocysteine (Hcy).

2.2.2. Neuropsychological cognitive assessment

Cognitive assessment was conducted by professionally trained personnel in a quiet, distraction-free environment on a one-on-one basis. The specific assessment content was as follows: The Montreal Cognitive Assessment Scale (MoCA) was used to comprehensively evaluate the subjects' total score and dimensions such as visuospatial and executive function, attention, language function, abstract thinking, memory, and orientation.

2.2.3. Eye-tracking detection

Eye movement detection was performed using the NW-PAD-2022V1.0 intelligent eye-tracking cognitive assessment system, which relies on the front camera of an ordinary Android tablet to achieve AI-assisted eye-tracking functionality with a sampling frequency of no less than 30 Hz. During detection, the distance between the subject and the device was controlled within 0.3–0.8 m, with a positioning error of no more than 1 cm, and the entire detection process took approximately 5 minutes per session.

The specific detection tasks included two items:

(1) Visual pairing task: During the encoding phase, 5 groups of pictures were presented sequentially, with each group displayed for 5 seconds; during the recognition phase, new and old pictures were presented in a paired manner, and relevant eye movement parameters such as fixation duration and preference ratio were recorded.

(2) Antisaccade task: A total of 12 trials were set, requiring subjects to actively shift their gaze to the opposite side of the stimulus signal, and core detection indicators such as saccade error rate, latency, peak velocity, and gain ratio were recorded.

2.3. Statistical methods

Data analysis was performed using SPSS 27.0 software. Measurement data were expressed as mean ± standard deviation (SD) or median (quartile) [M (P25, P75)], with independent sample *t*-tests for normal distributions and Mann-Whitney U tests for non-normal distributions; count data were expressed as the number of cases (percentage), with χ^2 tests or Fisher's exact tests performed; correlation was analyzed using Spearman's rank correlation analysis. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Comparison of baseline data between the two groups

There were no statistically significant differences in gender, hypertension, diabetes, atrial fibrillation, past medical history, BMI, homocysteine, fasting blood glucose, and uric acid between the two groups (all $P > 0.05$), as shown in **Table 1**.

Table 1. Comparison of baseline data between the two groups of subjects

Item	Healthy Control Group (n = 30)	CSVD Group (n = 51)	t/χ^2	*P*
Gender (male, n, %)	2 (6.7)	26 (51.0)	0.92	0.34
Age (years)	57.63 ± 8.92	63.90 ± 7.94	3.27	0.002
Hypertension (n, %)	19 (63.3)	37 (72.5)	0.75	0.386
Type 2 diabetes (n, %)	4 (13.3)	13 (25.5)	1.69	0.194
Atrial fibrillation (n, %)	0 (0.0)	1 (2.0)	-	0.630[1]
History of stroke (n, %)	2 (6.7)	13 (25.5)	4.45	0.035
Coronary heart disease (n, %)	2 (6.7)	7 (13.7)	0.00	0.96
Smoking history (n, %)	3 (10.7)	8 (16.3)	0.46	0.5
Drinking history (n, %)	1 (10.0)	2 (3.9)	0.84	0.36
BMI (kg/m^2)	25.02 ± 3.23	23.82 ± 2.96	1.72	0.09
Homocysteine (μmol/L)	14.74 ± 5.83	14.93 ± 5.64	0.15	0.89
Fasting glucose (mmol/L)	5.21 ± 2.06	4.86 ± 1.11	0.87	0.39
Uric acid (μmol/L)	303.74 ± 79.54	313.12 ± 76.55	0.53	0.6

Notes: (1) Due to the theoretical frequency of the atrial fibrillation indicator being less than 5, Fisher's exact test was used; (2) Smoking history: There were 28 valid cases in the healthy control group and 49 valid cases in the cerebral small vessel disease group (the rest were missing values); (3) Alcohol consumption history: There were 10 valid cases in the healthy control group (the rest were missing values); (4) Categorical variables are expressed as n (%), and the χ^2 test was used. Continuous variables are expressed as "mean ± standard deviation (SD)", and the independent samples t-test was used; (5) *P*-value less than 0.05 indicates a statistically significant difference.

3.2. Comparison of eye movement indicators between the two groups

The saccade error rate in the CSVD group was significantly higher than that in the control group ($P = 0.009$). There were no statistically significant differences between the groups in terms of latency, correct rate of error correction, saccade velocity, saccade gain, gaze duration on new/old images, total mean gaze duration, and the number of blinks during gaze (all $P > 0.05$). See **Table 2**.

Table 2. Comparison of eye movement indicators between the two groups

Variable	Healthy Control Group (n = 30)	CSVD Group (n = 51)	Statistic	*P*
Delay time (ms)	268.63 (226.37, 329.78)	314.63 (229.86, 524.08)	625	0.172
Error rate (%)	0.45 ± 0.28	0.61 ± 0.24	-2.696	0.009
Error correction accuracy (%)	0.42 (0.21, 0.59)	0.34 (0.17, 0.42)	740	0.189
Correction delay (ms)	303.53 (232.70, 349.49)	322.99 (272.88, 420.56)	506	0.229
Average velocity (pixel/ms)	1.41 (1.22, 1.65)	1.36 (1.14, 1.73)	838.5	0.475
Maximum velocity (horizontal) (pixel/ms)	2.67 (2.23, 3.52)	2.48 (2.06, 3.67)	814.5	0.632
Fixation blink count	0.00 (0.00, 0.00)	0.00 (0.00, 0.09)	634.5	0.086
Saccade gain (initial)	-0.33 (-6.93, 3.78)	0.05 (-4.55, 4.78)	721	0.671
Saccade gain (terminal)	-14.11 ± 66.71	2.75 ± 58.73	-1.186	0.239
Saccade error rate (corrected) (%)	0.91 (0.75, 1.00)	0.84 (0.65, 1.00)	844	0.429
Correct saccade latency (corrected) (ms)	369.26 (302.00, 501.75)	441.62 (312.94, 612.14)	621	0.202
Correct saccade latency (ms)	369.26 (302.00, 501.75)	441.62 (312.94, 612.14)	621	0.202
Average dwell time on new images (ms)	4512.75 (3058.55, 4958.23)	4307.20 (3214.05, 5026.00)	752	0.903
Average dwell time on old images (ms)	1832.95 (1546.35, 3328.35)	2062.70 (1451.10, 3360.00)	763	0.988

Variable	Healthy Control Group (n = 30)	CSVD Group (n = 51)	Statistic	*P*
Total average gaze duration (ms)	6509.35 (6213.18, 6999.53)	6596.00 (6031.50, 7040.80)	724	0.692
Fixation blink count	0.00 (0.00, 0.00)	0.00 (0.00, 0.09)	634.5	0.086

Notes: (1) Normally distributed data are presented as "mean ± standard deviation," while non-normally distributed data are shown as "median (interquartile range)." (2) The choice of statistical method is based on the results of the Shapiro-Wilk test for normality; for normally distributed data, an independent samples *t*-test is used, whereas for non-normally distributed data, the Mann-Whitney U test is applied. (3) A statistically significant difference is defined as $P < 0.05$.

3.3. Comparison of MoCA cognitive scores between the two groups

The CSVD group had significantly lower total MoCA scores, as well as lower scores in visuospatial and executive function, attention function, and language function compared to the control group (all $P < 0.05$). There were no significant differences in abstraction function, memory function, or orientation function scores between the two groups (all $P > 0.05$).

Table 3. Comparison of MoCA scale scores in each dimension between the two groups [M(P25,P75)]

Item	Healthy Control Group (n =3 0)	CSVD Group (n = 51)	U	*P*
MoCA total score	26.0 (25.0, 27.0)	24.0 (21.2, 26.0)	1145.5	<0.001
Visuospatial and Executive Function score	5.0 (4.0, 5.0)	3.0 (2.0, 4.0)	1145	<0.001
Attention score	6.0 (5.0, 6.0)	5.0 (5.0, 6.0)	985.5	0.004
Language score	6.0 (6.0, 6.0)	6.0 (5.0, 6.0)	892	0.039
Abstraction score	2.0 (1.0, 2.0)	1.0 (1.0, 2.0)	843.5	0.171
Memory score	4.0 (4.0, 4.0)	4.0 (3.0, 4.0)	880	0.094
Orientation score	5.0 (5.0, 5.0)	5.0 (5.0, 5.0)	713.5	0.876

Note: The data in the table are presented as median (interquartile range), and the Mann-Whitney U test was used; a statistically significant difference is defined as $P < 0.05$. MoCA: Montreal Cognitive Assessment.

3.4. Correlation between saccade error rate and cognitive scores

Spearman rank correlation analysis revealed a moderate negative correlation between saccade error rate and total MoCA score (rs = -0.382, $P = 0.0005$); a significant negative correlation with visuospatial and executive function scores (rs = -0.313, $P = 0.005$); and no significant correlation with attention, language, abstract, memory, or orientation function scores (all $P > 0.05$). Additionally, there was no correlation between saccade error rate and the severity of CSVD burden (rs = -0.001, $P = 0.996$). See **Tables 4, 5, and 6** for details.

Table 4. Correlation analysis between error rate and total MoCA score

Analysis Indicator	Statistical Method	Correlation Coefficient	*P*	Significance
Error Rate (%) vs. MoCA Total Score	Spearman	-0.382	0.0005	Yes

Note: Since the total MoCA score data exhibit a non-normal distribution ($P < 0.001$), the non-parametric Spearman rank correlation analysis method was employed.

Table 5. Correlation analysis between error rate and scores in each cognitive domain of the MoCA

Item	Correlation coefficient (r_s)	*P*
Visuospatial and Executive Function Score	-0.313	0.005
Attention Function Score	-0.07	0.539

Item	Correlation coefficient (r_s)	*P*
Language Function Score	-0.176	0.122
Abstract Function Score	-0.087	0.445
Memory Function Score	-0.113	0.321
Orientation Function Score	-0.149	0.190

Note: Spearman rank correlation analysis was applied; MoCA refers to the Montreal Cognitive Assessment; a statistically significant difference is defined as $P < 0.05$.

Table 6. Correlation analysis between eye movement error rate and severity grading of CSVD burden in the CSVD patient group

Statistical Indicator	Value
Sample size (n)	51
Correlation coefficient (rs)	-0.001
P	0.996

Note: Spearman rank correlation analysis was used; CSVD refers to cerebral small vessel disease; a *P*-value < 0.05 indicates a statistically significant difference.

4. Discussion

CSVD is one of the primary vascular causes of cognitive impairment, often co-occurring with Alzheimer's disease, imposing substantial medical and economic burdens on patients' families and society, and representing a key public health issue requiring urgent attention [4]. Mild cognitive impairment serves as a transitional stage between normal aging and dementia, and early identification and intervention can effectively delay disease progression. Eye movement behavior, regulated by multiple cognitive-motor networks, directly reflects core cognitive functions, with abnormalities closely associated with pathological changes in brain function. Eye-tracking technology has thus emerged as a focal area of research in cognitive impairment studies. Research has confirmed that patients with CSVD exhibit specific eye movement abnormalities, primarily characterized by an increased error rate in antisaccades, which is negatively correlated with cognitive function and visuospatial executive function impairments, underscoring the value of this technology in cognitive assessment for CSVD [5].

Eye movement abnormalities are closely linked to structural damage in neural circuits within the brain [6]. This study found that the eye movement error rate in the CSVD group was significantly higher than that in the healthy control group, with no significant intergroup differences in other eye movement metrics, suggesting that eye movement abnormalities in CSVD primarily affect inhibitory control functions while sparing basic motor eye movement functions. The core mechanism lies in the fact that antisaccade tasks rely on the fronto-parietal-subcortical inhibitory control network, and typical pathological changes in CSVD are prone to damaging this pathway, leading to decreased inhibitory control function and, consequently, an increased eye movement error rate [7].

Cognitive function assessment revealed that the total MoCA score in the CSVD group was significantly lower than that in the healthy control group, with cognitive impairments primarily concentrated in three cognitive domains: visuospatial and executive function, attention function, and language function, while abstraction thinking, memory, and orientation functions showed no significant abnormalities. This pattern

aligns with the clinical characteristics of CSVD-related cognitive impairments [8]. CSVD-induced white matter lesions are prone to affecting cognitive-related nerve fibers in deep brain regions and the brainstem, with the fronto-parietal network and thalamocortical pathways being particularly vulnerable to ischemic damage, whereas brain regions associated with memory and orientation functions are less affected in the early stages. This pattern is consistent with previous studies, confirming the reliability of the assessment results.

This study found that the eye movement error rate exhibited a moderate negative correlation with the total MoCA score and a significant negative correlation with visuospatial executive function scores, with no significant associations with other cognitive domains, suggesting its specific reflective value for this type of cognitive impairment. The core mechanism is that CSVD-induced damage to the fronto-parietal-subcortical network both increases the eye movement error rate and impairs visuospatial executive function, sharing a consistent pathological basis. The corrected saccade error rate results corroborate this finding, suggesting that eye movement inhibitory control indicators could serve as potential biomarkers [9,10]. Additionally, no significant correlation was observed between the eye movement error rate and CSVD burden, likely due to the small sample size and concentrated lesion grading, necessitating further validation with larger samples.

The core value of this study lies in clarifying the application prospects of eye-tracking technology in cognitive impairment assessment for CSVD. Traditional neuropsychological scales currently relied upon in clinical practice have numerous limitations and are ill-suited for early screening needs at the grassroots level. Eye-tracking technology is non-invasive, objective, portable, and efficient, making it suitable for elderly individuals with low education levels who are at high risk. This study confirms that the eye movement error rate can serve as an objective indicator to assist traditional scales in improving early identification accuracy. Combined with multimodal approaches, it holds promise for widespread application across multiple scenarios, facilitating the achievement of "early identification, early intervention" goals.

This study also has certain limitations, manifested in the following aspects: (1) The sample size was limited, and the single-center design introduced selection bias; (2) Only a single core eye movement indicator was validated, without forming a multidimensional biomarker combination; (3) Screening performance evaluations such as sensitivity, specificity, and ROC curves were not conducted; (4) Long-term follow-up to verify prognostic value was not performed. Future research should involve larger samples, multi-center, prospective studies to establish normative data for the Chinese population, optimize AI algorithms, and promote device miniaturization and clinical translation.

5. Conclusion

In summary, patients with CSVD exhibit specific eye movement abnormalities, primarily characterized by an increased antisaccade error rate. The saccade error rate shows a significant negative correlation with the total MoCA score and visuospatial and executive function, serving as an objective biomarker reflecting CSVD-related cognitive impairment. Eye-tracking technology is non-invasive, efficient, and objective, making it suitable for early screening and dynamic monitoring of CSVD-related cognitive impairment, with significant clinical translation prospects.

Funding

Key Research and Development Program of Shaanxi Province (Project No.: 2023-YBSF-033); Science and Technology Development Incubation Fund Project of Shaanxi Provincial People's Hospital (Project No.: 2023-YJY-72)

Disclosure statement

The authors declare no conflict of interest.

References

[1] Zanon ZMC, Sveikata L, Viswanathan A, et al., 2021, Cerebral Small Vessel Disease and Vascular Cognitive Impairment: From Diagnosis to Management. Current Opinion in Neurology, 34(2): 246–257.

[2] Miao S, Ji P, Zhu Y, et al., 2025, The Construction and Application of a Clinical Decision Support System for Cardiovascular Diseases: Multimodal Data-Driven Development and Validation Study. JMIR Medical Informatics, 13: e63186.

[3] Ling Y, Sun P, Wang C, et al., 2026, A Novel Eye-Tracking Digital Marker Outperforms Plasma Biomarkers in Detecting Cognitive Impairment. Alzheimer's & Dementia, 22(3): e71253.

[4] Markus HS, de Leeuw FE, 2023, Cerebral Small Vessel Disease: Recent Advances and Future Directions. International Journal of Stroke, 18(1): 4–14.

[5] Wang LS, Song JQ, Lv Y, 2023, Preliminary Establishment of a Logistics Regression Model for Diagnosing Alzheimer's Disease Based on Eye-Tracking Technology. Journal of Army Medical University, 45(2): 102–110.

[6] Ye J, Zhou L, Li Q, et al., 2026, Dysfunction of Hippocampal Cells and Its Role in Cognitive Impairment. Neural Regeneration Research, 21(8): 3479–3495.

[7] Opwonya J, et al., 2022, Saccadic Eye Movement in Mild Cognitive Impairment and Alzheimer's Disease: A Systematic Review and Meta-Analysis. Neuropsychology Review, 32(2): 193–227.

[8] Ma J, Liu F, Yang B, et al., 2021, Selective Aberrant Functional–Structural Coupling of Multiscale Brain Networks in Subcortical Vascular Mild Cognitive Impairment. Neuroscience Bulletin, 37(3): 287–297.

[9] Wang M, Yin X, Yin CY, et al., 2025, The Role of Saccade Characteristics in Early Diagnosis and Symptom Assessment of Parkinson's Disease. Chinese Journal of Geriatric Heart Brain Vessel Diseases, 27(12): 1611–1616.

[10] Godwin HJ, Hout MC, Barnhart AS, 2025, Pay Attention to Eye Movement Behavior. Behavioral and Brain Sciences, 48: e141.