

DESCRIPTION

TITLE OF INVENTION: [EPILEPSY PREDICTION METHOD AND SYSTEM BASED ON MULTI-BRAIN REGION COMPREHENSIVE ANALYSIS]

[0001] This application claims the priority of Chinese invention patent application 202411376519X, titled "Epilepsy Prediction Method and System Based on Multi-Brain Region Comprehensive Analysis", filed on September 30, 2024, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to the technical field of epilepsy detection, and specifically relates to an epilepsy prediction method and system based on multi-brain region comprehensive analysis.

BACKGROUND

[0003] Epilepsy is a neurological disorder of the brain caused by abnormal brain activity, characterized by recurrent seizures and a persistent tendency, affecting individuals across all age groups, with the number of cases showing a continuous increasing trend in recent years. Predicting epileptic seizures may reduce the risk of injury caused by the onset of the disease and help improve the prognosis of patients.

[0004] In current clinical diagnosis of epilepsy, doctors primarily rely on prolonged video and electroencephalogram (EEG) synchronous monitoring to record the seizure symptoms of patients, thereby determining the type of epilepsy. As EEG is non-invasive and may provide global information about the brain, it is widely used in epilepsy seizure prediction research. However, in practice, synchronously reviewing patient seizures and EEG states through video and EEG software often requires significant time, and the accuracy and efficiency of manual monitoring gradually decline over time. Additionally, diagnosing and treating by identifying abnormal EEGs to determine brain discharge areas and abnormalities places relatively high demands on the professional expertise of doctors.

[0005] To address the existing shortcomings, some studies have proposed using artificial intelligence to predict the probability of epileptic seizures. For example, the

literature *A Review of Research on Epileptic Seizure Prediction Based on Artificial Intelligence* (published in April of 2024) suggests that compared to classical machine learning models with manually extracted features, deep learning technology holds greater value in epileptic seizure prediction. However, this literature technique relies on analyzing multiple epileptic EEG datasets. In particular, the literature points out that unprocessed EEG signals contain various artifacts, which are divided into physiological artifacts (electrical signals generated by eye movements, heartbeats, etc.) and non-physiological artifacts (interference from the external environment). Therefore, preprocessing of the collected EEG is necessary to minimize or eliminate the impact of these artifacts. Thus, although this literature utilizes artificial intelligence means, the data analyzed remains EEG-based. Accordingly, there is a need to propose improvements based on the current situation.

SUMMARY

[0006] In view of the above, an objective of the present invention is to provide an epilepsy prediction method and an epilepsy prediction system based on multi-brain region comprehensive analysis, so as to alleviate or partially alleviate the existing deficiencies in the art, with the specific technical solution as follows.

[0007] An epilepsy prediction method based on multi-brain region comprehensive analysis, wherein the epilepsy prediction method is implemented based on an epilepsy prediction system for multi-brain region comprehensive analysis, the epilepsy prediction system comprises:

[0008] a signal acquisition module, configured to collect characteristic signals of a monitored subject under different saccade task paradigms, the characteristic signals comprising saccade task parameters;

[0009] an information preprocessing module, connected to the signal acquisition module, configured to organize, classify, and preliminarily screen the characteristic signals collected by the signal acquisition module;

[0010] an information screening and analysis module, connected to the preprocessing module, configured to establish a first logistic regression model, and further screen the preliminarily screened saccade task parameters; also configured to establish a second logistic regression model, for integrating the screened saccade task parameters and an output result of the first logistic regression model;

[0011] a data output module, connected to the information screening and analysis module, configured to output a result of the second logistic regression model, the result being a probability of epilepsy based on multi-brain region comprehensive analysis;

[0012] wherein the epilepsy prediction method comprises:

[0013] S01: collecting, in the signal acquisition module, saccade task parameters of the subject under different saccade task paradigms, the saccade task comprising prosaccade task, antisaccade task, memory-guided saccade task, and double-step saccade task, and other possible saccade tasks;

[0014] S02: organizing, classifying, and preliminarily screening, in the information preprocessing module, the collected saccade task parameters of the subject under different saccade tasks, preliminarily screening out saccade task parameters that have differences between subjects, preferably saccade task parameters with significant differences; the subjects comprising patients with epilepsy and healthy volunteers;

[0015] S03: establishing, in the information screening and analysis module, a single saccade task paradigm logistic regression model based on each saccade task paradigm in S01;

[0016] S04: combining, in the information screening and analysis module, the saccade task parameters preliminarily screened in S02 to obtain multiple datasets comprising different saccade task parameters, the datasets comprising both speed-type parameter and space-type parameter;

[0017] S05: inputting, in the information screening and analysis module, the multiple datasets into the single saccade task paradigm logistic regression model respectively, and outputting a first result of each model, the first result being a probability of epilepsy based on a single saccade task paradigm;

[0018] S06: calculating, in the information screening and analysis module, AUC of the probability of epilepsy based on a single saccade task paradigm for each dataset, excluding a dataset with AUC less than 0.6; further reducing a static-type parameter in each dataset and obtaining a specific dataset comprising a specific saccade task parameter;

[0019] S07: inputting, in the information screening and analysis module, the saccade task parameters in the specific dataset into the single saccade task

paradigm logistic regression model, obtaining four specific saccade task paradigm models, outputting a second result of each model, the second result being a probability of epilepsy based on a single specific saccade task paradigm; and then establishing a comprehensive logistic regression model based on the second result of each specific saccade task paradigm model; the comprehensive logistic regression model is:

$$P = \frac{1}{1+e^{-(10.23-8.949P_{pro}-2.683P_{anti}-5.429P_{memory}-4.707P_{double})}};$$

[0020] wherein, P_{pro} represents a probability value of the subject with epilepsy based on the prosaccade task, P_{anti} represents a probability value of the subject with epilepsy based on the antisaccade task, P_{memory} represents a probability value of the subject with epilepsy based on the memory-guided saccade task, and P_{double} represents a probability value of the subject with epilepsy based on the double-step saccade task;

[0021] S08: outputting, in the data output module, a third result of the comprehensive logistic regression model, the third result being a probability of the subject with epilepsy based on multi-brain region comprehensive analysis.

[0022] Further, the specific saccade task parameter comprises: correct rate of prosaccade paradigm, average speed of antisaccade paradigm, spatial error of antisaccade paradigm, spatial error of memory-guided saccade paradigm, corrective saccade latency of memory-guided saccade paradigm, average speed of double-step saccade paradigm, and spatial error of double-step saccade paradigm;

[0023] Further, a logistic regression model of the saccade task paradigm comprises a prosaccade paradigm model.

[0024] Further, a logistic regression model of the saccade task paradigm comprises an antisaccade paradigm model.

[0025] Further, a logistic regression model of the saccade task paradigm comprises a memory-guided saccade paradigm model.

[0026] Further, a logistic regression model of the saccade task paradigm comprises a double-step saccade paradigm model.

[0027] Further, S06 further comprises reducing a static-type parameter in each dataset so that each dataset comprises no more than two static-type parameters.

[0028] Further, the information preprocessing module is further configured to exclude an interference signal, the interference signal comprising a signal that cause deviation and/or influence on a saccade result. For example, excluding the deviation and influence of gender, age, and/or education characteristics of patients with epilepsy and healthy volunteers on the saccade results.

[0029] An epilepsy prediction system for multi-brain region comprehensive analysis comprising:

[0030] a signal acquisition module, configured to collect characteristic signals of a monitored subject under different saccade task paradigms, the characteristic signals comprising saccade task parameters;

[0031] an information preprocessing module, connected to the signal acquisition module, configured to organize, classify, and preliminarily screen the characteristic signals collected by the signal acquisition module; also configured to exclude an interference signal;

[0032] an information screening and analysis module, connected to the preprocessing module, configured to establish a first logistic regression model, and further screen the preliminarily screened saccade task parameters based on the established first logistic regression model; also configured to establish a second logistic regression model, for integrating the screened saccade task parameters and an output result of the first logistic regression model;

[0033] a data output module, connected to the information screening and analysis module, configured to output a result of the second logistic regression model, the result being a probability of the subject having epilepsy based on multi-brain region comprehensive analysis.

[0034] Further, the subject comprises patients with epilepsy and healthy volunteers.

[0035] As used herein, the terms “probability of epilepsy”, “probability of having epilepsy”, “probability of the subject with epilepsy”, “probability of the subject having epilepsy”, and similar variations shall have the same meaning, unless otherwise specified.

[0036] As used herein, the terms “prosaccade”, “prosaccade task”, “prosaccade task paradigm”, “prosaccade paradigm”, and similar variations shall have the same meaning, unless otherwise specified.

[0037] As used herein, the terms “antisaccade”, “antisaccade task”, “antisaccade task paradigm”, “antisaccade paradigm”, and similar variations shall have the same meaning, unless otherwise specified.

[0038] As used herein, the terms “memory-guided saccade”, “memory-guided saccade task”, “memory-guided saccade task paradigm”, “memory-guided saccade paradigm”, and similar variations shall have the same meaning, unless otherwise specified.

[0039] As used herein, the terms “double-step saccade”, “double-step saccade task”, “double-step saccade task paradigm”, “double-step saccade paradigm”, and similar variations shall have the same meaning, unless otherwise specified.

[0040] Beneficial Technical Effects

[0041] The epilepsy prediction method based on multi-brain region comprehensive analysis provided by the present invention differs from the current mainstream methods that use electroencephalogram (EEG) information for epilepsy analysis and prediction, by utilizing saccade artifacts that are even considered to be excluded in mainstream research, to address the prediction problem of whether a subject has epilepsy. The method provided by the present invention involves relatively complex parameter screening and model training, aiming to obtain more accurate and objective prediction results.

[0042] First, since different saccade parameters correspond to functional analysis of different brain regions, the method of the present invention performs multiple exclusions and screenings of saccade task parameters, forming a dataset including specific saccade parameters. Second, the present invention also constructs multiple logistic regression models aimed at achieving comprehensive prediction of multi-brain region epilepsy seizures. Since the brain regions analyzed by different saccade paradigms overlap, compared to epilepsy prediction based on a single saccade paradigm, the system and method based on multi-brain region comprehensive analysis provided by the present invention have higher prediction accuracy, providing guidance for reducing missed diagnoses and misdiagnoses of epilepsy. Additionally, the collection of saccade signals/parameters offers greater convenience, shorter operational time cycles, and relatively lower requirements for experimental personnel.

[0043] Since different diseases may cause overlapping brain region abnormalities, different diseases may involve examining the same saccade paradigms. For example, prior art discloses a set of biomarkers for detecting migraines and a method thereof, which uses prosaccade paradigm, antisaccade paradigm, memory-guided saccade paradigm, and double-step saccade paradigm to analyze the probability of migraine occurrence. However, different saccade parameters within the same saccade paradigm reflect different functional manifestations of brain regions, so screening accurate and specific saccade parameters is essential for predicting different diseases. The saccade parameters disclosed in the prior art include latency of prosaccade, interrupted fixation rate of prosaccade, latency of antisaccade, correct rate of memory-guided saccade, latency of memory-guided saccade, final saccade landing error of double-step saccade, and interrupted fixation rate of double-step saccade, all of which are static-type parameters. In contrast, the epilepsy prediction method and system based on multi-brain region comprehensive analysis provided by the present invention include multiple speed-type and space-type parameters, which are pioneering in the field of epilepsy prediction.

DESCRIPTION OF DRAWINGS

[0044] To make the embodiments of the present invention or the technical solutions in the prior art clearer, the drawings required to be used in the description of the embodiments or the prior art will be briefly introduced below. In all drawings, similar elements or components are generally identified by similar reference numerals. In the drawings, each element or component may not be drawn in actual proportion. It is obvious that the drawings described below are some embodiments of the present invention, and that other drawings can be obtained from these drawings for those of ordinary skill in the art without making inventive effort.

[0045] FIG. 1 is a schematic diagram of an epilepsy prediction system based on multi-brain region comprehensive analysis according to the present invention.

[0046] FIG. 2 is a schematic diagram of an epilepsy prediction method based on multi-brain region comprehensive analysis according to the present invention.

[0047] FIG. 3 shows significance test results of saccade task parameters under a prosaccade task paradigm in one embodiment of the present invention.

[0048] FIG. 4 shows significance test results of saccade task parameters under an antisaccade task paradigm in one embodiment of the present invention.

[0049] FIG. 5 shows significance test results of saccade task parameters under a memory-guided saccade task paradigm in one embodiment of the present invention.

[0050] FIG. 6 shows significance test results of saccade task parameters under a double-step saccade task paradigm in one embodiment of the present invention.

[0051] FIG. 7 is an ROC curve for determining epilepsy using a comprehensive logistic regression model in one embodiment of the present invention.

[0052] FIG. 8 is an ROC curve for diagnosing epilepsy using composite saccade parameters in one embodiment of the present invention.

DETAILED DESCRIPTION

[0053] To make the objective, the technical solutions and advantages of the embodiments of the present invention clearer, the technical solutions of the embodiments of the present invention will be clearly and completely described below in combination with drawings. It is obvious that the described embodiments are some of the embodiments of the present invention, not all of the embodiments. Based on the embodiments of the present invention, all other embodiments obtained by those of ordinary skill in the art without making inventive effort shall belong to the protection scope of the present invention.

[0054] As used herein, the term “and/or” refers to any and all combinations of one or more of the associated listed items.

[0055] As used herein, “a plurality of” means two or more, including but not limited to two, three, four, five, and so on.

[0056] It should be noted that the term “include”, “comprise” or any variant thereof is intended to encompass nonexclusive inclusion so that a process, method, article or device including a series of elements includes not only those elements but also other elements which have been not listed definitely or an element(s) inherent to the process, method, article or device. Moreover, the expression “comprising a(n) . . . ” in which an element is defined will not preclude presence of an additional identical

element(s) in a process, method, article or device comprising the defined element(s) unless further defined.

[0057] Term Explanation

[0058] The term "static-type parameter" described in the present invention include correct rate, latency, average number of saccade steps, non-reactive saccade rate, blink rate, occurrence rate of erroneous reflexive saccades accompanied by corrective saccades, corrective saccade latency, etc., under various saccade paradigms.

[0059] The term "speed-type parameter" described in the present invention include average speed, maximum rate, etc., under various saccade paradigms.

[0060] The term "space-type parameter" described in the present invention include spatial error, first saccade amplitude, corrective saccade spatial error, landing error, etc., under various saccade paradigms.

[0061] Embodiment 1

[0062] The present embodiment provided a system and method for determining whether a subject with epilepsy.

[0063] An epilepsy prediction system based on multi-brain region comprehensive analysis, the schematic diagram of which is shown in FIG. 1, comprises: a signal acquisition module, configured to collect characteristic signals of a monitored subject under different saccade task paradigms, the characteristic signals comprising saccade task parameters;

[0064] a signal acquisition module, configured to collect characteristic signals of a monitored subject under different saccade task paradigms, the characteristic signals comprising saccade task parameters;

[0065] an information preprocessing module, connected to the signal acquisition module, configured to organize, classify, and preliminarily screen the characteristic signals collected by the signal acquisition module; also configured to exclude an interference signal;

[0066] an information screening and analysis module, connected to the preprocessing module, configured to establish a first logistic regression model, and further screen the preliminarily screened saccade task parameters based on the established first logistic regression model; also configured to establish a second logistic regression model, for integrating the screened saccade task parameters and

an output result of the first logistic regression model; the second logistic regression model being:

$$P = \frac{1}{1 + e^{-(10.23 - 8.949P_{pro} - 2.683P_{anti} - 5.429P_{memory} - 4.707P_{double})}}$$

[0067] wherein P_{pro} represents a probability value of the subject with epilepsy based on a prosaccade task, P_{anti} represents a probability value of the subject with epilepsy based on an antisaccade task, P_{memory} represents a probability value of the subject with epilepsy based on a memory-guided saccade task, and P_{double} represents a probability value of the subject with epilepsy based on a double-step saccade task;

[0068] a data output module, connected to the information screening and analysis module, configured to output a result of the second logistic regression model.

[0069] An epilepsy prediction method based on the above system, the schematic diagram of which is shown in FIG. 2, includes:

[0070] S01: collecting saccade task parameters of a subject under different saccade task paradigms.

[0071] S02: preliminarily screening out saccade task parameters that have differences between patients with epilepsy and healthy volunteers, for example, parameters with significant differences.

[0072] S03: establishing a single saccade task paradigm logistic regression model.

[0073] S04: combining the preliminarily screened saccade task parameters to obtain multiple datasets comprising saccade task parameters; wherein each dataset should comprise both speed-type parameter and space-type parameter.

[0074] S05: inputting the dataset comprising saccade task parameters into the single saccade task paradigm logistic regression model, and outputting a first result, wherein the first result is a probability value of epilepsy.

[0075] S06: further screening the dataset based on the first result to obtain a specific dataset comprising a specific saccade task parameter; the screening process includes: 1) calculating AUC of the probability value of epilepsy based on a single saccade task paradigm and excluding a dataset with AUC less than 0.6; 2) further reducing a static-type parameter in the dataset.

[0076] S07: inputting the specific saccade task parameter into the single saccade task paradigm logistic regression model to obtain a specific saccade task paradigm model, outputting a second result, and establishing a comprehensive logistic regression model based on the second result.

[0077] S08: outputting a third result of the comprehensive logistic regression model.

[0078] The following embodiment provides a specific implementation process example based on the system and method provided in the present embodiment.

[0079] Embodiment 2

[0080] 1. Study Subjects: Patients with epilepsy aged 18 to 67 years who voluntarily participated in the study and signed informed consent forms were recruited from the outpatient department of West China Hospital of Sichuan University. Healthy controls (HC) matched with the patients in terms of gender, age, and education level were recruited from Chengdu and surrounding communities. Data including age, gender, vital signs, marital status, education level, lifestyle, dietary habits, age of epilepsy onset, pain location, nature, triggers, presence of aura, disease course, treatment, and family history were collected from the subjects, and saccade behavioral tests were conducted. Exclusion Criteria: Ophthalmic diseases affecting the test (such as blindness, obvious atrophy of one or both eyes, glaucoma, severe inflammation of eye-related tissues, retinal detachment), organic neurological and psychiatric diseases (such as cerebral infarction, cerebral hemorrhage, brain tumors, dementia, claustrophobia, schizophrenia, and moderate to severe anxiety and depression), and headaches caused by drug overuse. This study was approved by the Ethics Committee of West China Hospital of Sichuan University.

[0081] 2. Saccade Behavioral Examination: All subjects voluntarily signed informed consent forms. In a relatively quiet and dark environment, data on subject visual acuity, visual field, and four different saccade task paradigms (prosaccade P_{pro} , antisaccade P_{anti} , memory-guided saccade P_{memory} , and double-step saccade P_{double}) were collected. Main indicators observed included the correct rate, latency, saccade amplitude, average saccade speed, maximum saccade speed, spatial error, occurrence rate of multi-step saccades, accuracy, and corrective saccade latency and corrective saccade amplitude gain for antisaccade and memory-guided saccade

paradigms. Calibration and calibration verification were performed before each saccade behavioral test. Each subject underwent 12 practice trials before the formal task began. Each subject performed 40 formal trials under each task.

[0082] 3. Preliminary Data Screening and Exclusion: The saccade data processing workflow focuses on improving data quality and analysis accuracy. For blink data, a strategic approach is adopted: during phases with frequent or significant blink interference, data is selectively skipped or only marked, and not directly used for core analysis to avoid blink artifacts. This is because blinks create artifacts in the trajectory that resemble two saccades, which differ from actual saccades in speed, acceleration, and duration, thus requiring exclusion. Meanwhile, for other noise data, methods such as interpolation and filtering are applied for correction or elimination, ensuring the continuity and accuracy of the remaining data.

[0083] 4. Statistical Analysis: (1) Test whether the matching factors and other basic information of the two subject groups (for categorical variables such as gender and education level, using chi-square test), as well as parameters such as correct rate, latency, and final landing error of the four saccade task paradigms, meet the assumptions of normal distribution and homogeneity of variance. If all assumptions are met, use T-test; if normality is met but homogeneity of variance is not, use Welch test; if the requirements for parametric tests are not met, use the non-parametric U-test. (2) To compare whether there are differences in various parameters of the four saccade task paradigms between the two groups, the deviation and influence of gender, age, and education level on saccade results were removed, as the two groups showed no statistically significant differences in gender, age, or education level.

[0084] Embodiment 3

[0085] 1. Comparison of Clinical Data of Subjects: A total of 100 epilepsy subjects were recruited. Some subjects were excluded due to incomplete saccade tasks, resulting in 92 subjects ultimately included in the analysis. Details are shown in Table 1.

[0086] Table 1 Comparison of General Characteristics Between Epilepsy Group and Control Group

Item	Epilepsy Group (n=92)	Control Group (n=92)	P-value
Gender (Male, %)	22 (23.9)	21 (22.8)	0.862
Education Primary School (%)	11	11	0.342
Junior High School (%)	13	6.5	
High School/Technical Secondary School (%)	25	20.6	
College and Above (%)	51	61.9	
Age (Years, Mean $\pm$ Standard Deviation)	33.05 $\pm$ 10.15	32.77 $\pm$ 10.36	0.749

[0087] 2. Comparison of Saccade Parameters Between the Two Groups: Overall, the latency of prosaccades and antisaccades in the epilepsy group was prolonged compared to the control group, with statistically significant differences ($P < 0.05$). Additionally, the final landing error of double-step saccades in the epilepsy group was significantly larger than that in the control group ($p < 0.05$). Furthermore, from the perspective of stimulus direction, in relatively complex saccade paradigms (memory-guided saccade and double-step saccade), the final landing error of patients with epilepsy varied across different directions, suggesting that the differences may be related to the location of brain function impairment. No statistically significant differences were observed between the two groups in terms of saccade amplitude, average saccade speed, maximum saccade speed, occurrence rate of multi-step saccades, accuracy, landing error, corrective saccade latency, or corrective saccade amplitude gain.

[0088] Overall, the correct rates of the four task paradigms in the epilepsy group were lower than those in the control group, and the spatial errors were larger than those in the control group, with all results showing statistically significant differences ($p < 0.05$). The results are detailed in Tables 2-5.

[0089] Table 2 Details of Significant Parameters in Prosaccade Paradigm: Epilepsy Group vs. Control Group

Paradigm	Feature	Control Group	Epilepsy Group	H	p
	Break	8.125 $\pm$ 8.066	8.455 $\pm$ 8.811	4120.5	0.93943

Prosaccade (pro)	Error Rate	14.047±10.489	19.409±14.432	3202.5	0.01134
	First Saccade Amplitude	9.195±0.726	8.95±0.956	4682	0.0952
	Occurrence Rate of Multi-step Saccades	10.062±9.817	16.83±16.649	2944.5	0.0011
	Spatial Error	1.035±0.934	1.079±0.344	3183	0.00973
	Landing Error	0.971±0.281	1.089±0.341	3284	0.02153
	Average Speed	148.908±29.958	155.393±21.837	3429	0.05915
	Latency	220.466±28.736	224.906±44.687	4052	0.90513
	Non-reactive Saccade Rate	0.115±0.542	0.5±1.727	3844	0.11299
	Average Number of Saccade Steps	1.111±0.113	1.185±0.195	2983.5	0.00161
	Blink Rate	1.987±4.838	5.072±8.487	2997.5	p<0.001
	Correct Rate	0.86±0.105	0.806±0.144	4985.5	0.01134
	Maximum Speed	369.027±69.258	367.83±58.47	3945	0.67243

[0090] Table 3 Details of Significant Parameters in Antisaccade Paradigm:
Epilepsy Group vs. Control Group

Paradigm	Feature	Control Group	Epilepsy Group	H	p
Antisaccade (anti)	Break	7.609±8.418	12.756±14.783	3268	0.02421
	Error Rate	39.629±24.336	51.756±27.359	2986.5	0.00238
	Occurrence Rate of Erroneous Reflexive Saccades Accompanied by Corrective Saccades	99.774±1.558	98.568±6.225	4283	0.07497
	First Saccade Amplitude	9.46±2.711	10.198±2.689	3198	0.04747
	Occurrence Rate of Multi-step Saccades	47.38±21.606	42.545±20.193	4396.5	0.11731
	Duration from Reflex End to Saccade End	276.25±74.646	319.401±103.158	2893	0.00531
	Reflexive Saccade	0.77±0.16	0.764±0.314	4197	0.26946

	Amplitude Gain				
	Average Number of Reflexive Saccade Steps	1.047±0.107	1.137±0.339	3225.5	0.03389
	Reflexive Saccade Latency	252.313±44.269	243.466±69.914	4344.5	0.12246
	Directional Error Saccade Rate / Reflexive Error Saccade Rate	28.389±24.244	34.22±26.745	3527	0.13593
	Number of Corrective Saccade Steps	1.575±0.342	1.766±0.47	2939	0.00799
	Corrective Saccade Amplitude Gain	1.073±0.368	1.053±0.276	3808.5	0.95597
	Corrective Saccade Spatial Error	0.415±2.748	0.302±3.22	3900	0.82752
	Corrective Saccade Landing Error	3.702±4.24	3.671±1.922	3450	0.2605
	Corrective Saccade Latency	117.53±50.578	142.645±76.021	3128.5	0.03709
	Spatial Error	2.646±0.744	3.514±1.396	2217	p<0.001
	Landing Error	2.777±0.892	3.784±2.104	2435	p<0.001
	Average Speed	124.597±27.796	135.417±27.209	2890	0.0038
	Latency	362.586±68.289	366.582±102.076	3988	0.72128
	Non-reactive Saccade Rate	0.383±1.252	0.627±2.829	3983.5	0.72926
	Average Number of Saccade Steps	1.601±0.337	1.564±0.323	4150	0.40295
	Blink Rate	2.723±5.725	8.979±16.111	3017	0.00126
	Correct Rate	0.604±0.243	0.482±0.274	5109.5	0.00238
	Maximum Speed	329.948±74.172	344.657±69.561	3352	0.12697

[0091] Table 4 Details of Significant Parameters in Memory-Guided Saccade

Paradigm: Epilepsy Group vs. Control Group

Paradigm	Feature	Control Group	Epilepsy Group	H	p
Memory-Guided Saccade (memory)	Break	20.714±17.788	28.904±22.77	3153.5	0.01022
	Error Rate	28.364±20.815	43.128±27.1	2670.5	p<0.001
	Occurrence Rate of Erroneous Reflexive Saccades Accompanied by Corrective Saccades	4.632±9.424	14.124±18.848	2076	p<0.001
	First Saccade Amplitude	8.446±1.16	8.463±1.487	3958	0.99884
	Occurrence Rate of Multi-step Saccades	24.986±18.223	25.985±16.908	3768.5	0.58031
	Reflexive Saccade Amplitude Gain	0.595±0.267	0.737±0.194	1248	p<0.001
	Reflexive Saccade Latency	384.142±213.504	418.583±144.889	1636.5	0.06833
	Corrective Saccade Latency	192.536±136.157	260.026±112.585	1176	p<0.001
	Spatial Error	1.741±0.488	2.221±0.877	2362	p<0.001
	Landing Error	1.798±0.503	2.351±1.059	2451	p<0.001
	Average Speed	118.45±26.154	122.561±23.906	3589	0.28228
	Latency	340.376±73.331	358.334±85.499	3430	0.12407
	Non-reactive Saccade Rate	5.143±10.049	12.054±18.809	2913.5	0.00117
	Average Number of Saccade Steps	1.276±0.214	1.294±0.191	3655.5	0.3779
	Blink Rate	6.353±16.621	10.703±21.105	3372	0.03426
	Correct Rate	0.716±0.208	0.569±0.271	5428.5	p<0.001
	Maximum Speed	307.627±65.314	314.203±74.167	3899	0.86254

[0092] Table 5 Details of Significant Parameters in Double-Step Saccade

Paradigm: Epilepsy Group vs. Control Group

Paradigm	Feature	Control Group	Epilepsy Group	H	p
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Double-Step Saccade (double)	Break	5.299±6.439	8.068±10.806	3493.5	0.10565
	Error Rate	41.623±18.668	56.41±24.895	2586.5	p<0.001
	First Saccade Amplitude	9.088±1.172	9.001±1.433	4209	0.55023
	Occurrence Rate of Multi-step Saccades	46.887±26.736	44.914±27.19	4196	0.57553
	Spatial Error	2.671±0.633	3.244±1.262	2592	p<0.001
	Spatial Error_1	2.521±0.916	3.178±1.384	2808	p<0.001
	Landing Error	2.995±0.839	3.644±1.593	2731	p<0.001
	Average Speed	143.405±33.037	152.872±25.332	3262	0.03271
	Latency	284.984±89.525	269.692±81.665	4404	0.24597
	Non-reactive Saccade Rate	0.061±0.415	0.45±2.316	3904	0.2186
	Average Number of Saccade Steps	2.669±0.498	2.665±0.566	4154.5	0.65984
	Blink Rate	8.55±17.889	18.561±24.565	3023	0.00242
	Correct Rate	0.584±0.187	0.436±0.249	5509.5	p<0.001
	Maximum Speed	344.51±78.039	340.061±59.21	4111	0.75308

Note: Spatial Error_1 is defined as the spatial error at the first target during the double-step saccade task.

[0093] The different saccade tasks involved in Tables 2-5 are described as follows.

[0094] Prosaccade Task: Used as a tool to assess cognitive function. This task evaluates the brain's processing speed and accuracy by measuring rapid eye movements (i.e., saccades), thereby indirectly reflecting the state of cognitive function.

[0095] Antisaccade Task: A psychological experiment used to study cognitive control and executive function. In this task, participants are required to ignore a suddenly appearing stimulus and make a saccade in the opposite direction to the stimulus. This task tests the participant's ability to inhibit a prepotent response and execute a controlled response.

[0096] Memory Saccade Task: Also known as the memory-guided saccade task, it is a psychological experiment that tests an individual's memory and visuospatial processing abilities. In this task, participants must first remember the location of a target that appears randomly in the visual field. After the target disappears, they must maintain attention during a delay period and then accurately move their gaze to

the previous target location without visual cues. This task is primarily used to assess the integration of memory, attention, and spatial orientation abilities.

[0097] Double-Step Saccade Task: An experimental paradigm used to study saccade control and related cognitive functions, typically employed to investigate how the brain plans and executes rapid target localization activities.

[0098] The following shows examples of multiple saccade task parameter combinations obtained during the preliminary screening stage of the method of the present invention.

[0099] Table 6 Saccade Task Parameter Combinations

Dataset	Prosaccade Paradigm	Antisaccade Paradigm	Memory-Guided Saccade Paradigm	Double-Step Saccade Paradigm
1	Blink Rate	Correct Rate, Landing Error	Spatial Error, Landing Error	Spatial Error, Landing Error
2	Correct Rate	Average Speed, Spatial Error	Spatial Error, Reflexive Saccade Amplitude Gain	Blink Rate, Spatial Error
3	Correct Rate	Average Speed, Spatial Error	Spatial Error, Corrective Saccade Latency	Average Speed, Spatial Error
4	Correct Rate, Multi-Step Saccade	Landing Error, Correct Rate	Spatial Error	Average Speed, Spatial Error, Blink Rate

[0100] It is to be understood that the content shown in Table 6 is for illustrative purposes only rather than limiting.

[0101] Embodiment 4

[0102] Establishing a logistic regression model using the data collected and organized from Embodiment 2 and Embodiment 3, for predicting epilepsy in subjects.

[0103] (1) Collecting saccade task parameters of volunteers and patients with epilepsy under the four saccade task paradigms, in the signal acquisition module.

[0104] (2) Organizing, classifying, and preliminarily screening the collected saccade task parameters, in the information preprocessing module, preliminarily screening out saccade task parameters with significant differences between subjects ($p < 0.05$).

[0105] (3) Establishing four saccade task paradigm logistic regression models based on the four saccade task paradigms, in the information screening and analysis module, represented as P_{pro} , P_{anti} , P_{memory} , and P_{double} .

[0106] (4) Combining the saccade task parameters with significant differences preliminarily screened by the system, to obtain multiple datasets including different saccade task parameters, in the information screening and analysis module.

[0107] (5) Inputting the multiple datasets into the single saccade task paradigm logistic regression model respectively, and outputting the first result of each model, in the information screening and analysis module, the first result being the probability value of epilepsy based on a single saccade task paradigm.

[0108] (6) Calculating the AUC of the probability value of epilepsy based on a single saccade task paradigm for each dataset, excluding datasets with AUC less than 0.6; further excluding static-type parameters in the datasets, such that the entire dataset includes no more than two static-type parameters; finally obtaining a specific dataset including specific saccade task parameters, the specific saccade task parameters being correct rate_{pro}, average speed_{anti}, spatial error_{anti}, average speed_{double}, spatial error_{double}, spatial error_{memory}, corrective saccade latency_{memory}.

[0109] (7) Inputting the saccade task parameters in the specific dataset into the single saccade task paradigm logistic regression model, obtaining four specific saccade task paradigm models, outputting the second result of each model, in the information screening and analysis module, the second result being the probability value of epilepsy based on a single specific saccade task paradigm, as follows:

[0110] Prosaccade paradigm model:

$$P_{pro} = \frac{1}{1 + e^{-(3.30 - 3.76X_1)}}$$

[0111] P_{pro} represents the posterior probability of the subject having epilepsy as determined by the prosaccade, and X_1 represents the correct rate of the prosaccade. After calculation, the AUC value of P_{pro} is 0.628.

[0112] Antisaccade paradigm model:

$$P_{anti} = \frac{1}{1 + e^{-(3.17 + 0.014X_1 + 0.53X_2)}}$$

[0113] P_{anti} represents the posterior probability of the subject having epilepsy as determined by the antisaccade, X_1 represents the average speed of the antisaccade,

and X_2 represents the spatial error of the antisaccade. After calculation, the AUC value of P_{anti} is 0.703.

[0114] Memory-guided saccade paradigm model:

$$P_{memory} = \frac{1}{1 + e^{-(-2.938 + 1.095X_1 + 0.004X_2)}}$$

[0115] P_{memory} represents the posterior probability of the subject having epilepsy as determined by the memory-guided saccade, X_1 represents the spatial error of the memory-guided saccade, and X_2 represents the corrective saccade latency of the memory-guided saccade. After calculation, the AUC value of P_{memory} is 0.750.

[0116] Double-step saccade paradigm model:

$$P_{double} = \frac{1}{1 + e^{-(-5.06 + 0.018X_1 + 0.898X_2)}}$$

[0117] P_{double} represents the posterior probability of the subject having epilepsy as determined by the double-step saccade, X_1 represents the average speed of the double-step saccade, and X_2 represents the spatial error of the double-step saccade. After calculation, the AUC value of P_{double} is 0.703.

[0118] To further quantify the probability determination of the four saccade paradigms, a comprehensive logistic regression model is established based on the second results of each specific saccade task paradigm model; the comprehensive logistic regression model is as follows:

$$P = \frac{1}{1 + e^{-(-10.23 - 8.949P_{pro} - 2.683P_{anti} - 5.429P_{memory} - 4.707P_{double})}}$$

[0119] (8) Outputting the third result of the comprehensive logistic regression model, the third result being the probability of the subject with epilepsy based on multi-brain region comprehensive analysis.

[0120] After calculation, the sensitivity of the constructed comprehensive logistic regression model for determining whether a subject with epilepsy is 77.4%, the specificity is 73.1%, and the area under the curve (AUC) is 0.82.

[0121] Sensitivity and specificity are important indicators for evaluating the performance of epilepsy prediction models. Sensitivity measures the true positive rate (TPR), while specificity measures the true negative rate (TNR). The ROC curve evaluates the TPR and false positive rate (FPR) during the interictal and preictal periods of epilepsy. AUC ranks the performance of classification algorithms based

on TPR and FPR. The AUC value ranges from 0 to 1, with a higher AUC value indicating better performance of the classification algorithm.

[0122] The following shows the predicted probability of having epilepsy for three healthy volunteers and three patients with epilepsy based on the above models.

[0123] Table 7 Probability Prediction of Epilepsy in Different Subjects

Subject ID	Subject Group	P _{pro}	P _{anti}	P _{memory}	P _{double}	P
01	Epilepsy Group	45.895%	31.630%	51.712%	24.913%	34.779%
02		41.466%	37.156%	62.403%	57.434%	55.642%
03		45.987%	6.941%	6.811%	42.734%	17.358%
04	Control Group	45.521%	61.760%	48.359%	34.367%	46.851%
05		49.599%	65.046%	12.833%	74.878%	48.123%
06		41.466%	62.300%	43.781%	66.163%	58.624%

[0124] Based on the results shown in Table 7, the probabilities of whether a subject has epilepsy obtained from different saccade paradigm models vary significantly. The comprehensive logistic regression model may quantify these differences to some extent, providing guidance for reducing missed diagnoses and misdiagnoses of epilepsy.

[0125] Embodiment 5

[0126] A quantitative analysis was conducted on the seven saccade parameters finally screened in Embodiment 4 to examine the effect sizes of these parameters between the control group and the epilepsy group. The results are shown in Table 8.

[0127] Table 8 Quantitative Analysis of Saccade Parameters

Saccade Paradigm	Saccade Parameter	Epilepsy Group	Control Group	P	Effect Size (RBC)
Prosaccade	Correct Rate	80.591±14.351	85.953±10.432	0.011385719	0.217757694
Antisaccade	Average Speed	135.417±27.049	124.597±27.643	0.003822295	0.252747253
	Spatial Error	3.514±1.387	2.646±0.74	1.03E-06	0.426761474
Double-Step Saccade	Average Speed	152.872±25.186	143.405±32.856	0.032824847	0.184907546
	Spatial Error	3.244±1.255	2.671±0.629	4.74E-05	0.352323838

Memory-Guided Saccade	Spatial Error	2.221±0.872	1.741±0.485	3.41E-06	0.403309334
	Corrective Saccade Latency	260.026±111.8	192.536±134.936	5.52E-05	0.416666667

[0128] The correct rate primarily reflects cognitive function; average speed mainly reflects executive function and information processing-related functions; spatial error primarily reflects motor control and spatial computation-related functions; corrective saccade latency mainly reflects attention, inhibitory function, and executive-related functions. The above results indicate that patients with epilepsy show significant differences from normal individuals mainly in motor function and executive function. Analysis of brain regions controlling motor function and executive function may be used to effectively predict whether a subject has epilepsy.

[0129] Embodiment 6

[0130] Composite Saccade Parameters as Biomarkers for Diagnosing Epilepsy

[0131] Experimental Methods

[0132] 1. Study Subjects:

[0133] Adult patients with epilepsy who voluntarily participated in the study and signed informed consent forms were recruited from the outpatient department of West China Hospital, Sichuan University. Healthy control subjects matched with the patients in terms of gender, age, and education level were recruited from communities around West China Hospital. General data such as age, gender, vital signs, education level, lifestyle, dietary habits, age of epilepsy onset, location of epileptic foci, triggers of epilepsy, disease course, treatment, and family history were collected from the subjects. Saccade behavioral tests were conducted. Exclusion Criteria: Ophthalmic diseases affecting the test (such as blindness, obvious atrophy of one or both eyes, glaucoma, severe inflammation of eye-related tissues, retinal detachment), organic neurological and psychiatric diseases (such as cerebral infarction, cerebral hemorrhage, brain tumors, dementia, claustrophobia, schizophrenia, and moderate to severe anxiety and depression), and headaches drug overuse. This study was approved by the Ethics Committee of West China Hospital of Sichuan University.

[0134] 2. Saccade Behavioral Examination

[0135] An infrared video-based eye tracker with a sampling rate of 1000 Hz per eye was used to monitor eye position. Visual stimuli were presented on a 27-inch LCD monitor located 57 cm in front of the participants (monitor resolution: 1920 × 1080 pixels, refresh rate: 100 Hz). Before each session, a 9-point (3 × 3 matrix) eye position calibration and validation procedure was performed to ensure the accuracy of eye position measurements. Each participant completed four tasks: prosaccade (PS), antisaccade (AS), memory-guided saccade (MGS), and double-step saccade (DS) tasks (FIG. 1). At the beginning of each trial, participants were required to fixate on a white cross (fixation point) displayed at the center of the screen. If the participant's gaze remained within a 4° fixation window for 800 ms, the cross disappeared, and task-specific visual stimuli appeared. In the PS, AS, and MGS tasks, a white dot (diameter 1°) randomly appeared at one of four peripheral positions (left, right, up, or down, with an eccentricity of 10°). In the PS task, participants made a saccade toward the direction of the visual stimulus, whereas in the AS task, participants were required to look toward the mirror position of the visual stimulus. The MGS task required participants to saccade to the remembered location where the visual stimulus had previously appeared. In the DS task, two consecutive visual stimuli briefly appeared, and participants needed to perform two consecutive saccades in the order of the visual stimuli's appearance. All experiments were conducted by trained personnel who were not involved in medical history or questionnaire collection.

[0136] 3. Analysis of Saccade Parameters

[0137] Across the PS, AS, MGS, and DS tasks, a total of 52 relevant parameters were calculated (13 per task). The parameters most strongly correlated with outcomes in this study, i.e., those showing differences between patients with epilepsy and healthy controls, were as follows: 1) Correct Rate (%): The proportion of correct trials among all trials. 2) Break-Fixation Rate (%): The proportion of trials where fixation was broken prematurely during the preparation or memory maintenance phase, leading to task interruption or trial invalidation. 3) Saccade Amplitude (°): The angular displacement of the primary saccade, measured in degrees of visual angle. 4) Primary Spatial Error (°): The distance between the landing point of the first reflexive saccade and the target location. 5) Multi-Step Saccade (%): The proportion of trials where multi-step saccades occurred. 6)

Average Speed (°/ms): The average speed of the first primary saccade or the main saccade.

[0138] 4. Criteria for Correct Task Execution

[0139] For a task to be judged as correctly executed, the following conditions had to be met: The amplitude of the primary saccade had to be greater than 2°, and the saccade direction had to be toward the target location (or the correct mirror location in the antisaccade task). The endpoint of the saccade had to fall within a predefined error threshold for the target position. The specific thresholds were as follows: Prosaccade task < 3.25°, Antisaccade task < 6.75°, Memory-guided saccade task < 4.5°. Given the complexity of the double-step saccade task, which involves two consecutive stimuli, no endpoint error threshold was set for it. These thresholds were empirically determined based on the parameter distribution of the control group (mean $\pm$ 1.96 $\times$ standard deviation).

[0140] 5. Statistical Analysis

[0141] Demographic characteristics and saccade parameters were compared between patients with epilepsy and healthy controls. Continuous variables are expressed as mean $\pm$ standard deviation, while categorical variables are expressed as counts (percentages). Variables with normal distribution and homogeneity of variance were analyzed using independent samples t-tests; otherwise, the Mann-Whitney U test was applied. Categorical variables were analyzed using Pearson chi-square tests or Fisher's exact test, as appropriate.

[0142] Normalized Asymmetry Index Analysis

[0143] To further investigate whether directional asymmetry exists in saccades among patients with epilepsy (PWE), the asymmetry index for each horizontal saccade parameter was calculated using the formula: $\text{Asymmetry} = |x - y|/\sqrt{2}$ (in PWE, x and y represent saccade parameters directed toward the ipsilateral and contralateral hemispheres relative to the epileptic focus, respectively; in healthy controls (HC), x and y represent saccade parameters directed toward the left and right sides, respectively). A smaller asymmetry value indicates less asymmetry between the two directions of horizontal saccades. To facilitate cross-parameter comparisons, the asymmetry value for each parameter was normalized to the range [0, 1], resulting in the Normalized Asymmetry Index (NAI), calculated as: $\text{NAI} = (X -$

$X_{\min}) / (X_{\max} - X_{\min})$, where X represents the current parameter value, and $X_{\min}$ and $X_{\max}$ represent the minimum and maximum values of that parameter, respectively.

[0144] Results

[0145] 1. Comparison of Clinical Data of Subjects

[0146] A total of 165 epilepsy subjects and 163 healthy subjects as controls were recruited. However, due to some subjects not completing the saccade tasks, 145 epilepsy subjects and 145 matched healthy control subjects were included in the analysis. The matching principle ensured that there were no statistically significant differences in gender, education level, or age between the epilepsy group and the control group ($P > 0.05$).

[0147] 2. Comparison of Saccade Parameters Between the Two Groups

[0148] Overall, the latency of prosaccades and antisaccades in the epilepsy group was prolonged compared to the control group, with statistically significant differences. Additionally, the final landing error of double-step saccades in the epilepsy group was significantly larger than that in the control group. Furthermore, from the perspective of stimulus direction, in relatively complex saccade paradigms (memory-guided saccade and double-step saccade), the final landing error of patients with epilepsy varied across different directions, suggesting that the differences may be related to the location of brain function impairment.

[0149] There were no statistically significant differences between the two groups in terms of saccade amplitude, average saccade speed, maximum saccade speed, occurrence rate of multi-step saccades, accuracy, landing error, corrective saccade latency, or corrective saccade amplitude gain.

[0150] 3. Sensitivity Analysis of Saccade Parameter Comparison Between the Two Groups

[0151] Comparing Table 9 and Table 10, it may be observed that regardless of whether propensity score matching or inverse probability weighting was used for subject matching, there were significant differences between the two groups in prosaccade latency, antisaccade latency, memory-guided saccade correct rate, as well as the correct rate and final landing error of double-step saccade, indicating high reliability of the detection results.

[0152] 4. Multiple Saccade Parameters for Diagnosing Epilepsy

[0153] Using the correct rate, latency, and final landing error from five paradigms to construct a logistic regression model for diagnosing epilepsy, the sensitivity was 77.4%, the specificity was 73.1%, and the area under the curve (AUC) was 0.82 (see FIG. 8).

[0154] Conclusion

[0155] Epilepsy is a complex lifelong disease, and changes in composite saccade parameters (first saccade amplitude_{pro}, landing error_{pro}, reflexive error saccade rate_{anti}, break_{anti}, landing error_{anti}, corrective saccade steps_{anti}, reflexive error saccade rate_{memory}, corrective saccade latency_{memory}, average speed_{double}, spatial error_{double}) may serve as biomarkers for diagnosing epilepsy.

[0156] Table 9 Comparison of General Characteristics Between Epilepsy Group and Control Group

	Epilepsy Group (n=145)	Control Group (n=145)	P Value
Gender (Male, %)	22 (23.9)	21 (22.8)	0.862
Age (Years, Mean (IQR))	33.68 (24-42)	33.61 (25-42)	0.749
Education			
Primary School (%)	11	11	0.342
Junior High School (%)	13	6.5	
High School/Technical Secondary School (%)	25	20.6	
College and Above (%)	51	61.9	
Drug-Resistant Epilepsy (%)	51 (34.6)	—	—
Disease Course	11.62 (4.0-16.75)	—	—
Epilepsy Type (%)			
Generalized	33 (22.9)	—	—
Focal	96 (65.6)	—	—
Unknown	16 (11.5)	—	—
Epilepsy Etiology (%)			
Known	60 (42.1)	—	—
Unknown	85 (57.9)	—	—

[0157] Table 10 Comparison of Saccade Parameters Between Epilepsy Group and Control Group in Four Saccade Tasks

Parameters of Task ^a	All Participants (n=290)	PWE Group (n=145)	HC Group (n=145)	P Value
Prosaccade Task				
Accuracy (%)	88.1±10	88.3±10.1	87.9±9.9	0.54
Non-reactive saccade rate (%)	0.167±0.832	0.219±1.028	0.116±0.574	0.25

Incubation period (ms)	208.436±34.677	213.28±43.992	203.657±20.883	0.21
Average speed (°/ms)	158.863±26.939	162.781±23.784	154.998±29.241	<0.0001***
Maximum speed (°/ms)	390.565±74.306	396.376±69.914	384.831±78.054	<0.01*
Saccade amplitude (°)	9.068±0.876	8.939±0.999	9.195±0.713	<0.001**
Mean saccade count (n)	1.169±0.158	1.203±0.177	1.136±0.128	<0.0001***
Multiple step saccades (%)	14.972±13.356	17.716±14.723	12.265±11.231	<0.0001***
First-step spatial error (°)	1.053±0.481	1.131±0.42	0.975±0.523	<0.0001***
Blink rate (%)	3.09±8.509	3.708±9.295	2.48±7.617	<0.01*
Break rate (%)	7.793±7.882	7.607±7.837	7.976±7.931	0.45
Saccadic endpoint error (°)	1.058±0.377	1.142±0.41	0.976±0.321	<0.0001***
Antisaccade Task				
Accuracy (%)	61.6±25.4	59.5±25.3	63.7±25.4	<0.01*
Non-reactive saccade rate (%)	0.457±1.971	0.645±2.551	0.275±1.134	<0.01*
Incubation period (ms)	351.664±83.927	360.76±98.796	342.857±65.354	0.04*
Average speed (°/ms)	135.392±28.554	139.674±29.063	131.246±27.454	<0.0001***
Maximum speed (°/ms)	357.121±82.379	368.438±81.966	346.162±81.38	<0.0001***
Saccade amplitude (°)	9.837±2.772	10.057±2.896	9.623±2.632	0.02*
Mean saccade count (n)	1.62±0.342	1.653±0.358	1.588±0.323	<0.01*
Multiple step saccades (%)	45.819±19.968	46.966±20.096	44.709±19.803	0.06
First-step spatial error (°)	3.059±1.158	3.345±1.314	2.781±0.902	<0.0001***
Error rate of reflexive saccades (%)	28.638±23.833	30.148±23.727	27.176±23.87	0.01*
Blink rate (%)	4.696±11.614	6.198±13.65	3.238±8.995	<0.001**
Break rate (%)	10.268±11.507	12.304±12.646	8.29±9.901	<0.0001***
Saccadic endpoint error (°)	3.149±1.28	3.455±1.529	2.852±0.888	<0.0001***
Number of corrective saccades (n)	1.672±0.514	1.767±0.553	1.58±0.455	<0.0001***

Duration from reflexive saccade offset to saccade offset (ms)	301.528±96.221	320.871±96.481	282.678±92.248	<0.0001***
Corrective saccade landing error (°)	3.299±2.04	3.563±1.793	3.042±2.227	<0.0001***
Reflexive saccade latency (ms)	229.171±64.019	227.668±64.186	230.636±63.895	0.34
Amplitude gains of reflexive saccades	0.801±1.399	0.846±1.981	0.756±0.208	0.86
Latency of corrective saccades (ms)	137.506±71.244	149.91±74.138	125.418±66.187	<0.0001***
Memory-Guided Saccade Task				
Accuracy (%)	70.8±22.7	67.1±25	74.3±19.7	<0.001**
Non-reactive saccade rate (%)	5.73±10.801	7.264±13.047	4.269±7.843	<0.0001***
Incubation period (ms)	343.418±79.14	346.721±85.746	340.277±72.26	0.5
Average speed (°/ms)	123.391±24.746	124.638±25.532	122.205±23.944	0.15
Maximum speed (°/ms)	328.77±76.022	334.491±77.778	323.331±73.992	0.045*
Saccade amplitude (°)	8.377±1.398	8.223±1.579	8.524±1.183	<0.01*
Mean saccade count (n)	1.336±0.232	1.377±0.255	1.296±0.2	<0.0001***
Multiple step saccades (%)	28.814±17.826	31.242±18.657	26.506±16.693	<0.001**
First-step spatial error (°)	2.005±0.848	2.185±1.047	1.833±0.548	<0.0001***
Error rate of reflexive saccades (%)	8.596±12.714	12.596±15.523	4.784±7.523	<0.0001***
Blink rate (%)	5.33±12.997	6.97±15.333	3.764±10.052	<0.001**
Break rate (%)	22.768±19.409	26.948±21.401	18.774±16.347	<0.0001***
Saccadic endpoint error (°)	2.119±0.998	2.338±1.237	1.911±0.635	<0.0001***
Error rate of reflexive saccades (%)	8.596±12.714	12.596±15.523	4.784±7.523	<0.0001***
Reflexive saccade latency (ms)	390.987±194.21 8	403.325±172.77	377.093±215.27 1	<0.001**
Amplitude gains of reflexive saccades	0.704±0.363	0.738±0.277	0.665±0.438	<0.0001***

Latency of corrective saccades (ms)	233.623±129.54 9	255.153±117.45 7	209.376±138.15 8	<0.0001***
Double-Step Saccade Task				
Accuracy (%)	52.7±22.7	45.8±23.3	59.3±19.9	<0.0001***
Non-reactive saccade rate (%)	0.095±0.842	0.168±1.153	0.026±0.334	<0.01*
Incubation period (ms)	271.347±82.646	270.766±90.946	271.896±74.043	0.16
Average speed (°/ms)	154.036±30.801	159.843±30.095	148.543±30.485	<0.0001***
Maximum speed (°/ms)	357.661±80.256	366.144±80.068	349.636±79.695	<0.01*
Saccade amplitude (°)	8.994±1.396	8.955±1.568	9.031±1.211	0.53
Mean saccade count (n)	2.735±0.483	2.779±0.521	2.694±0.441	0.02*
Multiple step saccades (%)	50.556±24.871	51.763±26.14	49.414±23.58	0.13
First-step spatial error (°)	2.915±1.001	3.193±1.209	2.652±0.652	<0.0001***
Blink rate (%)	10.629±19.299	14.474±22.775	6.975±14.382	<0.0001***
Break rate (%)	6.723±9.012	7.624±10.028	5.867±7.842	<0.01*
Saccadic Spatial Error_1 ^b	2.799±1.231	3.023±1.328	2.588±1.092	<0.0001***
saccadic endpoint error (°)	3.337±1.372	3.686±1.601	3.007±1.008	<0.0001***

a. All results are presented as mean ± standard deviation (Mean ± SD).

Abbreviations: PWE, patients with epilepsy, HC, healthy control

* $P < 0.05$, ** $P < 0.001$, *** $P < 0.0001$

b. Spatial Error_1 is defined as the spatial error at the first target during the double-step saccade task.

[0158] The present embodiment employs a logistic regression algorithm for construction. The feature selection and modeling process includes the following steps: First, all saccade parameters that exhibited statistically significant differences between groups were selected as initial candidate predictors. Second, the variance inflation factor (VIF) was used in a collinearity diagnostic model to assess multicollinearity among these predictors. To eliminate high collinearity, predictors with a VIF greater than or equal to 10 were iteratively removed, and the diagnostics were rerun until all remaining features met the criterion of $VIF < 10$, indicating no significant multicollinearity. To ensure comparability of regression coefficients, all

candidate predictors intended for inclusion in the model were subsequently normalized, scaling their values to the range [0, 1]. Finally, these normalized and collinearity-free predictors were input into the logistic regression model. The final set of features included in the model was determined through an iterative validation process, retaining or excluding predictors based on their statistical significance in the model.

[0159] The final selected parameters consist of 10 in total, namely: first saccade amplitude_{pro}, landing error_{pro}, reflexive error saccade rate_{anti}, break_{anti}, landing error_{anti}, corrective saccade steps_{anti}, reflexive error saccade rate_{memory}, corrective saccade latency_{memory}, average speed_{double}, and spatial error_{double}.

[0160] Through the description of the above manners of implementation, persons skilled in the art can clearly understand that the above embodiment methods can be implemented through software and necessary general hardware platforms. Of course, they can also be done through hardware, but in many cases, the former is the preferred manner of implementation. Based on this understanding, the essence of the technical solutions of the present invention, or the part that contributes to the prior art, can be embodied in the form of a software product, which is stored in a storage medium (such as ROM/RAM, magnetic disk, optical disk) and comprises several instructions to enable a computer terminal (which can be a mobile phone, a computer, a server, or a network device, etc.) to perform the methods described in the embodiments of the present invention.

[0161] The embodiments of the present invention are described above with reference to the accompanying drawings, but the present invention is not limited to the aforementioned specific embodiments. The aforementioned embodiments are merely illustrative and not limiting. For those of ordinary skill in the art, many forms can be made under the teaching of present invention without departing from the spirit of the present invention and the scope of the claims, all of which shall fall within the protection scope of the present invention.

CLAIMS

Claim 1. An epilepsy prediction method based on multi-brain region comprehensive analysis, wherein the epilepsy prediction method is implemented based on an epilepsy prediction system for multi-brain region comprehensive analysis, the epilepsy prediction system comprising:

a signal acquisition module, configured to collect characteristic signals of a monitored subject under different saccade task paradigms, the characteristic signals comprising saccade task parameters;

an information preprocessing module, connected to the signal acquisition module, configured to organize, classify, and preliminarily screen the characteristic signals collected by the signal acquisition module;

an information screening and analysis module, connected to the preprocessing module, configured to establish a first logistic regression model, and further screen the preliminarily screened saccade task parameters; also configured to establish a second logistic regression model, for integrating the screened saccade task parameters and an output result of the first logistic regression model;

a data output module, connected to the information screening and analysis module, configured to output a result of the second logistic regression model, the result being a probability of epilepsy based on multi-brain region comprehensive analysis; wherein the epilepsy prediction method comprises:

S01: collecting, in the signal acquisition module, saccade task parameters of the subject under different saccade task paradigms, the saccade task comprising prosaccade task, antisaccade task, memory-guided saccade task, and double-step saccade task;

S02: organizing, classifying, and preliminarily screening, in the information preprocessing module, the collected saccade task parameters of the subject under different saccade tasks, preliminarily screening out saccade task parameters that have differences between subjects, the subjects comprising patients with epilepsy and healthy volunteers;

S03: establishing, in the information screening and analysis module, a single saccade task paradigm logistic regression model based on each saccade task paradigm in S01;

S04: combining, in the information screening and analysis module, the saccade task parameters preliminarily screened in S02 to obtain multiple datasets comprising different saccade task parameters, the datasets comprising both speed-type parameter and space-type parameter;

S05: inputting, in the information screening and analysis module, the multiple datasets into the single saccade task paradigm logistic regression model respectively, and outputting a first result of each model, the first result being a probability of epilepsy based on a single saccade task paradigm;

S06: calculating, in the information screening and analysis module, AUC of the probability of epilepsy based on a single saccade task paradigm for each dataset, excluding a dataset with AUC less than 0.6; further reducing a static-type parameter in each dataset so that each dataset comprises no more than two static-type parameters and obtaining a specific dataset comprising a specific saccade task parameter; the specific saccade task parameter comprises: correct rate of prosaccade paradigm, average speed of antisaccade paradigm, spatial error of antisaccade paradigm, spatial error of memory-guided saccade paradigm, corrective saccade latency of memory-guided saccade paradigm, average speed of double-step saccade paradigm, and spatial error of double-step saccade paradigm;

S07: inputting, in the information screening and analysis module, the saccade task parameters in the specific dataset into the single saccade task paradigm logistic regression model, obtaining four specific saccade task paradigm models, outputting a second result of each model, the second result being a probability of epilepsy based on a single specific saccade task paradigm; and then establishing a comprehensive logistic regression model based on the second result of each specific saccade task paradigm model;

the comprehensive logistic regression model is:

$$P = \frac{1}{1+e^{-(10.23-8.949P_{pro}-2.683P_{anti}-5.429P_{memory}-4.707P_{double})}};$$

wherein, P_{pro} represents a probability value of the subject with epilepsy based on the prosaccade task, P_{anti} represents a probability value of the subject with epilepsy based on the antisaccade task, P_{memory} represents a probability value of the subject with epilepsy based on the memory-guided saccade task, and P_{double} represents a probability value of the subject with epilepsy based on the double-step saccade task;

S08: outputting, in the data output module, a third result of the comprehensive logistic regression model, the third result being a probability of the subject with epilepsy based on multi-brain region comprehensive analysis.

Claim 2. The epilepsy prediction method based on multi-brain region comprehensive analysis according to claim 1, wherein a logistic regression model of the saccade task paradigm comprises a prosaccade paradigm model:

$$P_{pro} = \frac{1}{1 + e^{-(3.30 - 3.76X_1)}}$$

wherein X_1 represents a correct rate of prosaccade.

Claim 3. The epilepsy prediction method based on multi-brain region comprehensive analysis according to claim 1, wherein a logistic regression model of the saccade task paradigm comprises an antisaccade paradigm model:

$$P_{anti} = \frac{1}{1 + e^{-(-3.17 + 0.014X_1 + 0.53X_2)}}$$

wherein X_1 represents an average speed of antisaccade, and X_2 represents a spatial error of antisaccade.

Claim 4. The epilepsy prediction method based on multi-brain region comprehensive analysis according to claim 1, wherein a logistic regression model of the saccade task paradigm comprises a memory-guided saccade paradigm model:

$$P_{memory} = \frac{1}{1 + e^{-(-2.938 + 1.095X_1 + 0.004X_2)}}$$

wherein, X_1 represents a spatial error of memory-guided saccade, and X_2 represents a corrective saccade latency of memory-guided saccade.

Claim 5. The epilepsy prediction method based on multi-brain region comprehensive analysis according to claim 1, wherein a logistic regression model of the saccade task paradigm comprises a double-step saccade paradigm model:

$$P_{double} = \frac{1}{1 + e^{-(-5.06 + 0.018X_1 + 0.898X_2)}}$$

wherein X_1 represents an average speed of double-step saccade, and X_2 represents a spatial error of double-step saccade.

Claim 6. The epilepsy prediction method based on multi-brain region comprehensive analysis according to claim 1, wherein the information preprocessing module is further configured to exclude an interference signal, the interference signal comprising a signal that cause deviation and/or influence on a saccade result.