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Differences in EEG Microstate Induced by Gaming: A Comparison Between the Gaming Disorder Individual, Recreational Game Users and Healthy Controls

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ABSTRACT Excessive gaming can lead to gaming disorder, which affects the function and structure of the brain. In order to diagnose gaming disorders, it is of importance to understand how gaming behavior affects brain activity patterns and whether there exist differences in the effects on different individuals. Electroencephalogram (EEG) microstate reflects a transiently stable brain topological structure with spatiotemporal characteristics, and the spatial characteristic microstate classes and temporal parameters provide insight into the brain's functional activities in gaming disorders. In order to explore the feasibility of using EEG microstate parameters as markers of gaming addiction, in the present study, resting-state EEG data were acquired before and after playing video game for 30 minutes from 38 participants, containing gaming disorder individual (GD), recreational game users (RGU), and healthy controls (HC). Our study compared the microstate parameters before and after playing game among three groups. According to the results, the resting-state EEG microstate parameters exert no significant difference before playing game among three groups. However, we found significant difference in microstate B and D parameters among three groups after playing game. Additionally, compared with the pre-gaming, the post-gaming data showed that the variation trend of microstate B and D parameters of the three groups was similar. Moreover, these discoveries provide the first causal evidence of a microstate modification following gaming behavior interference, suggesting that microstates B and D are closely associated with gaming behavior, which can be used as EEG markers for distinguishing gaming addiction.

INDEX TERMS Gaming behavior, gaming disorder, microstate, resting-state EEG.

I. INTRODUCTION

World Health Organization (WHO) recognized "Gaming Disorder (GD)" as a mental illness and also included it in the 11th edition of the International Classification of Diseases (ICD-11) under the classification of "disorders caused by addictive behavior", alongside gambling disorder. Usually, GD is defined as an excessive or uncontrolled use of the game followed by negative consequences [1], [2]. Its diagnostic criteria are similar to substance use disorders and pathological gambling [3]–[5]. The criteria for judging Internet Gaming Disorder (IGD) are included in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) in 2013 [6], [7]. Governments and health agencies around the world are investigating how gaming behavior affects brain activity, looking for objective criteria for the diagnosis of GD and the development of preventive methods.

Neurophysiologists have gained insights into how the brain functions in a healthy state and how excessive gaming affect the brain function of people with gaming disorders. The research of functional magnetic resonance imaging (fMRI) has demonstrated that there exist functional connections between specific brain regions organized into networks [8]. These networks drive different types of brain

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functions, and their damage may be related to the pathophysiology of gaming disorder [9]–[12]. EEG is a powerful and popular method for rapid and non-invasive detection of network activity across the cerebral cortex in healthy and disease subjects. A recent survey concerning EEG-based Brain-Computer Interfaces (BCIs) has mentioned the application of EEG in medical treatment [13]. Any change in brain function or structure caused by any direct or indirect cause can lead to abnormal brain activity, which is reflected in the characteristic parameters and can be used to assist clinical diagnosis. Spontaneous brain activity in a resting-state is increasingly considered as an important indicator of the correlation between brain activity and cognitive behavior [14]. The use of resting-state EEG to investigate gaming disorder has been reported. In fact, coherence analysis of resting-state EEG showed that the increase of phase synchronization of beta and gamma coherence may be a core neurophysiological feature of GD [15], [16]. In IGD group, the interhemispheric coherence value of alpha band between FP1-FP2 electrodes was significantly lower [17]. Regarding the research of power spectrum, the correlation study of resting-state quantitative EEG proved that the lower absolute beta power could be used as a potential trait marker of GD [18]. Additionally, another quantitative EEG study suggested that the relative delta power was lower and the relative beta power was higher [19]. The microstate analysis is an alternative way to globally describe the resting-state brain activity [20].

EEG microstate analysis with inherent high temporal resolution and high test-retest reliability can test sub-second dynamic changes in brain activity [21]. The brain dynamic as detected by EEG can be globally described as a sequence of ''microstate'' [20], [22]. In microstate analysis, the EEG activity is segmented into periods of approximately 60–120 ms duration, in which distributed neural pools are synchronously active and generate fixed spatial potential topographies on the scalp. Consequently, a single microstate, corresponding to a specific EEG topographical map, may be associated with a ''quasi-stable'' functional state, in which the brain enters during a specific neural process [23]. As a result, the ongoing EEG time course can be represented by a non-casual sequence of such topographies without any type of a priori hypothesis [24]. In the healthy adult resting state, most of the variance of EEG signals has been demonstrated to be explained by sequences of four specific topographies (Fig. 1), labelled as A, B, C, D [20]. A and B had a nearly vertical orientation (respectively from left occipital-parietal to right fronto-central for A and the opposite for B), while C and D had a horizontal orientation (a symmetrical back to prefrontal orientation for C and a central positivity with an occipital to fronto-central symmetrical orientation for D). A large number of experiments have demonstrated that the microstates of four kinds of brain in resting state can be systematically extracted by cluster analysis, which can map approximately 70% of the global variance [25]. At present, a large number of researches based on the new direction of microstate analysis, in the process of demonstrating how the human brain processes

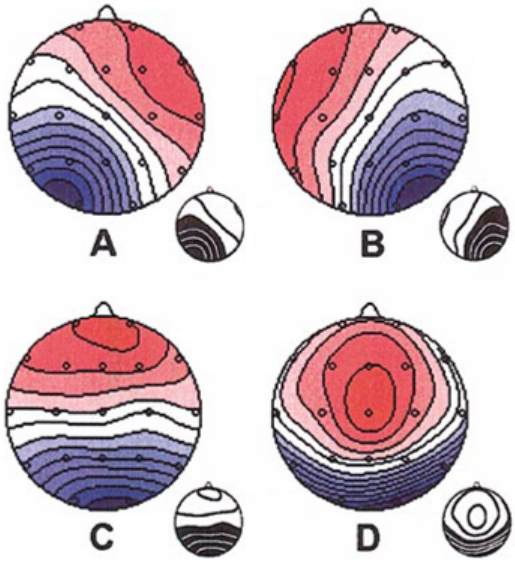

FIGURE 1. Microstate EEG topography, four common microstate scalp maps for 496participants, from (Koenig *et al.* 2002) [20].

information, are mainly concentrated on exploring the resting state of cognition and large-scale brain networks. Specially, its temporal dynamics, spatial organization and changes are caused by different cognitive disorders and neurological diseases [23].

The results of microstate analysis of EEG signals provide a lot of information about its potential clinical value [20]. An increasing number of studies have proved that there are significant differences in some specific characteristics between normal people and some substance addicts (e.g., heroin addiction, alcohol addiction, and tobacco addiction) in the microstate [26]–[28]. At present, there is no research on the microstate of gaming addiction. Methods like investigating substance addiction could also be used to explore gaming addiction. Existing studies on gaming addiction have shown that gaming behavior exerts an effect on the structure or function of the brain, and there are significant differences in some parameters of resting EEG between addicts and healthy subjects [29]–[32]. According to previous works, cognitive behavior can affect the resting brain activity pattern, which is reflected in the microstate parameters [33]. It can be hypothesized that gaming behavior, as a cognitive manipulation [34]–[36], may activate or inhibit the activity of some regions of the brain, and could lead to a global reorganization of the brain functional state. That leads to differences in microstate topographies patterns and characteristic parameters, and the influence on different groups may also be different [37].

To confirm the above hypothesis, we explored the feasibility of using EEG microstate parameters as markers of gaming addiction, and designed an experiment to collect the resting-state EEG data of three groups of subjects including GD, RGU, and HC. One part of data is before playing game, and the other is after 30 minutes of playing game. In addition,

TABLE 1. Demographic information and group differences.

	I GD (n=12)		II RGU (n=14)		III HC (n=12)		Statistic Value	
	Mean	SD	Mean	SD	Mean	SD	F	P
Age	23.00	2.35	23.15	3.18	22.42	2.27	0.534	0.591
Educations (years)	16.33	2.15	16.21	2.83	16.17	2.00	0.016	0.985
GAS score	59.17	9.78	30.57	5.75	21.75	1.96	106.428	0.000
DSM-5 score	27.92	2.71	13.50	3.50	10.75	1.91	129.008	0.000
Game playing per week (hours)	17.33	3.47	15.99	2.96	0.00	0.00	159.630	0.000

the changes of microstate parameters in two states and three groups were analyzed. The research found that the gaming behavior significantly affected the brain activity. There were significant differences in some microstate parameters between the two states, and there also existed significant differences between different groups of subjects.

II. MATERIALS AND METHOD

All the subjects filled in the informed consent form before participating in the experiment, which was approved by the Biomedical Ethics Committee of Hebei University of Technology (Approval number: HEBUThMEC2020002).

A. PARTICIPANTS

We recruited a total of 38 subjects and inquired about their health status and medical history through oral interviews. Then they filled in the Beck depression inventory (BDI) and Beck anxiety inventory (BAI) and thus we can simply evaluate their mental state. In addition, the subjects were required to fill in their name, sex, age, education, and the time of playing games per week. All the subjects who participated in the current experiment were right-handed, having normal intelligence with no history of mental illness.

Secondly, the subjects filled in the Gaming Addiction scale (GAS) adapted from the Internet addiction test (IAT) [38] and the revised version (five-level scoring) of the 9 diagnostic criteria for online gaming addiction recommended in the DSM-5. According to previous studies [29], [38]–[42], the subjects were divided into three groups: group I, GD; group II, RGU; group III, HC. Several studies used RGU as a control group, finding some abnormalities in gaming disorder that were different from using the general control group [30], [43]. Because addiction is a cumulative process, RGU may be between addicts and healthy controls [44]. The use of RGU in the research may provide a better way to understand the brain mechanism that can prevent RGU from developing GD [45]. The subjects who were categorized into the GD group should satisfy two criteria. First, they should have scored 50 or more on GAS. Second, they should have exhibited at least five of the nine IGD diagnostic criteria in the DSM-5 (i.e., DSM-5 score is more than 25). The RGU are those who frequently play online games without developing gaming addiction. The subjects should have played online games as frequently as the GD subjects and have no symptoms of physical or psychological dependence on online gaming. Their GAS score is less than 50 and the DSM-5 score is less than 20. The HC scored less than 30 points in GAS and 20 points in DSM-5. Importantly, they did not play online games. Assessed by BDI and BAI, all the subjects had no depression or anxiety. Table 1 shows the basic information and scale scores of the subjects in each group.

B. EXPERIMENTAL PROCEDURE

Subjects were seated in a comfortable armchair, and were collected the resting-state EEG data for 1min. After that, they played video game for about 30 minutes, and then we collected the resting-state EEG data again.

C. EEG SIGNAL RECORDING AND DATA PROCESSING

EEG data were recorded using a 64-channel Quick-cap system (Compumedics, Neuroscan). The sampling rate for EEG recording was 1000 Hz. The bandpass filter was set to 0.1–100 Hz and the impedance of all electrodes was <10 kΩ.

Recordings were first down-sampled to 500 Hz. Then, data were re-referenced to a common average reference and filtered using a bandpass frequency of 1–30 Hz. In addition, a semi-automatic procedure, based on Independent Component Analysis (ICA), was applied to identify and remove ocular, cardiac and muscular artefacts.

D. MICROSTATES EXTRACTION

The global field power (GFP) of the preprocessed EEG data was determined for each participant. The GFP of EEG at each time point is calculated by (1). In this equation, N represents the total number of electrodes, μ_i is the voltage of the i^{th} electrode at time t, and $\bar{\mu}$ signifies the average voltage of all electrodes at that time. GFP is an instantaneous reference-independent measure of neuronal activity throughout the brain, and it is calculated as the standard deviation of the electrical potential across all electrodes at each time point [32]. Since EEG map topographies remain stable around the GFP peaks and these are the best representatives of the topographic maps regarding SNR, only EEG topographies at the GFP peaks were submitted to perform further analysis. Subsequently, EEG data corresponding to the maxima

TABLE 2. Microstate metrics (mean and standard deviation) in the pre-gaming.

	I GD (n=12)		II RGU (n=14)		III HC (n=12)		Statistic Value		Post hoc
	Mean	SD	Mean	SD	Mean	SD	F	P	
Occurrence									
A	2.892	0.987	2.995	0.695	3.053	0.552	0.138	0.872	
B	3.178	0.417	3.104	0.568	3.078	0.731	0.095	0.909	
C	2.914	1.042	2.889	0.624	2.975	0.650	0.040	0.961	
D	3.599	0.767	3.456	0.678	3.360	0.579	0.377	0.689	
Duration									
A	69.410	8.933	74.036	13.704	75.572	8.539	1.057	0.358	
B	74.154	9.587	76.150	7.679	74.530	6.249	0.236	0.791	
C	71.906	12.359	78.799	13.915	79.662	14.541	1.184	0.318	
D	93.856	27.882	85.508	20.261	84.266	18.924	0.651	0.528	
Coverage									
A	0.207	0.089	0.228	0.086	0.234	0.061	0.379	0.687	
B	0.236	0.048	0.238	0.055	0.233	0.069	0.025	0.976	
C	0.218	0.099	0.233	0.080	0.244	0.090	0.253	0.778	
D	0.339	0.119	0.302	0.114	0.290	0.101	0.640	0.534	

of GFP were submitted to the clustering algorithm. Next, the data were run through the polarity-insensitive automatic agglomerate hierarchical clustering (AAHC) analyses [24]. To compare our results with previous studies, we selected four microstates from clustering analyses and labeled them A–D in accordance with their similarities to the previously reported microstate classes.

$$GFP\,(t) = \sqrt{\frac{\sum_{i=1}^{N}(\mu_i - \bar{\mu})^2}{N}} \tag{1}$$

Four microstate parameters were computed for each subject and compared in the current research including mean duration (Duration), time coverage (Coverage), frequency of occurrence (Occurrence), and transition probability (TP). Duration: average time covered by a single microstate class. Coverage: percentage of time covered by a single microstate class. Occurrence: mean number of distinct microstates of a given class occurring within a 1 second window. TP: the probability of transition from the current microstate to another state.

The analysis of microstate is realized by Matlab2019 (MathWorks, Natick, MA, USA) and EEGLAB toolbox.

E. STATISTICAL ANALYSIS

In order to compare the significant differences of microstate parameters among the three groups, one-way ANOVA was employed to analyze the microstate time series parameters of all subjects, and multiple comparisons were made between each two groups. Multiple comparison data are corrected by Bonferroni. The post-gaming microstate data were compared with the pre-gaming by paired T-test.

III. RESULT

We obtained the pre-gaming and post-gaming microstate topographic maps as shown in Fig. 2. That said, each subject has its own microstates A (MS-A), B (MS-B), C (MS-C) and D (MS-D), and these four microstates are extremely similar to the four previously marked brain topographic maps. The global explained variance (GEV) of brain topographic map before the game was 69.7% (group I 70.7%, group II 69.4%, group III 68.9%), and the global explained variance of post-gaming brain topographic map was 71.4% (group I 73.1%, group II 70.2%, group III 70.4%).

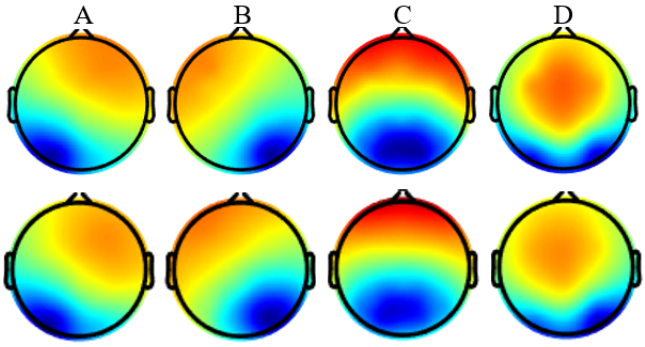

FIGURE 2. Microstate EEG topography (Up: pre-gaming; Down: post-gaming).

The one-way ANOVA of pre-gaming's microstates parameters are presented in Table 2 and Table 3 and post-gaming's microstates parameters are shown in Table 4 and Table 5. Summary statistics of the computed microstates parameters among three groups are shown in Fig. 3. Stars indicate significant differences.

As shown in Table 2 and III, there was no significant difference in microstate parameters among the three groups before the game ($p > 0.05$). However, in Table 4 and V, there were significant differences in several microstate parameters among the three groups after the game.

In terms of post-gaming microstate parameters, after post hoc range tests and pairwise multiple comparisons, we found that: MS-B's Coverage was significantly

TABLE 3. Microstate metrics (mean and standard deviation) in the pre-gaming.

TP	I GD (n=12)		II RGU (n=14)		III HC (n=12)		Statistic Value		Post hoc
	Mean	SD	Mean	SD	Mean	SD	F	P	
A to B	0.325	0.088	0.323	0.076	0.306	0.102	0.180	0.836	
A to C	0.291	0.123	0.301	0.092	0.322	0.113	0.256	0.776	
A to D	0.384	0.093	0.376	0.106	0.372	0.098	0.045	0.956	
B to A	0.299	0.114	0.320	0.110	0.303	0.079	0.142	0.868	
B to C	0.282	0.119	0.283	0.087	0.313	0.106	0.349	0.708	
B to D	0.419	0.161	0.397	0.138	0.384	0.111	0.194	0.824	
C to A	0.284	0.111	0.303	0.089	0.331	0.086	0.754	0.478	
C to B	0.302	0.062	0.311	0.081	0.307	0.085	0.040	0.961	
C to D	0.414	0.130	0.386	0.119	0.362	0.104	0.580	0.565	
D to A	0.318	0.121	0.336	0.117	0.324	0.054	0.110	0.896	
D to B	0.359	0.117	0.343	0.077	0.358	0.088	0.119	0.888	
D to C	0.324	0.119	0.321	0.090	0.319	0.108	0.006	0.994	

TABLE 4. Microstate metrics (mean and standard deviation) in the post-gaming.

	I GD (n=12)		II RGU (n=14)		III HC (n=12)		Statistic Value		Post hoc
	Mean	SD	Mean	SD	Mean	SD	F	P	
Occurrence									
A	3.111	0.647	2.923	0.666	3.099	0.476	0.384	0.684	
B	2.332	0.536	2.667	0.416	2.890	0.449	4.351	0.021*	$P_{I,III}$ =0.006*
C	2.432	1.056	3.031	0.876	2.914	0.684	1.615	0.213	
D	3.536	0.374	3.612	0.539	3.488	0.543	0.210	0.811	
Duration									
A	78.226	10.283	75.222	10.843	78.529	8.583	0.443	0.646	
B	68.363	4.355	74.307	9.838	70.021	7.291	2.113	0.136	
C	71.018	14.257	77.638	11.963	78.243	18.642	0.869	0.428	
D	116.299	40.736	92.331	17.588	88.625	14.020	3.940	0.029*	$P_{I,II}$=0.027*, $P_{I,III}$ =0.015*
Coverage									
A	0.247	0.079	0.224	0.068	0.245	0.056	0.493	0.615	
B	0.160	0.039	0.198	0.040	0.205	0.052	3.748	0.033*	$P_{I,II}$=0.032*, $P_{I,III}$ =0.017*
C	0.180	0.092	0.241	0.090	0.237	0.108	1.563	0.224	
D	0.414	0.152	0.337	0.096	0.313	0.084	2.580	0.090	$P_{I,III}$ =0.037*

TABLE 5. Microstate metrics (mean and standard deviation) in the post-gaming.

TP	I GD (n=12)		II RGU (n=14)		III HC (n=12)		Statistic Value		Post hoc
	Mean	SD	Mean	SD	Mean	SD	F	P	
A to B	0.329	0.102	0.306	0.073	0.322	0.068	0.280	0.756	
A to C	0.240	0.057	0.271	0.049	0.317	0.070	5.119	0.011*	$P_{I,III}$ =0.003*
A to D	0.430	0.131	0.423	0.086	0.362	0.082	1.718	0.194	
B to A	0.257	0.127	0.321	0.124	0.315	0.107	1.079	0.351	
B to C	0.219	0.065	0.268	0.060	0.275	0.076	2.508	0.096	$P_{I,III}$ =0.048*
B to D	0.524	0.153	0.411	0.128	0.410	0.111	3.042	0.061	$P_{I,II}$=0.036*, $P_{I,III}$ =0.041*
C to A	0.245	0.101	0.301	0.121	0.302	0.098	1.126	0.336	
C to B	0.316	0.092	0.286	0.097	0.302	0.062	0.405	0.670	
C to D	0.439	0.125	0.413	0.117	0.396	0.080	0.464	0.633	
D to A	0.284	0.103	0.368	0.130	0.321	0.106	1.733	0.192	
D to B	0.434	0.094	0.347	0.135	0.364	0.082	2.314	0.114	$P_{I,II}$ =0.047*
D to C	0.281	0.052	0.285	0.076	0.316	0.076	0.890	0.420	

smaller in I compared with II and III ($p_{I,II}$ =0.032∗, $p_{I,III}$ =0.017∗), as well as its Occurrence in I compared with III ($p_{I,III}$ =0.006∗). MS-D's Duration was significantly larger in I compared with II and III ($p_{I,II}$ =0.027∗, $p_{I,III}$ =0.015∗), as well as its Coverage in I compared with III ($p_{I,III}$ =0.037∗). TP_{AC} (Transition Probability of microstate A to microstate C)

was significantly smaller in I compared with III ($p=0.003*$), as well as TP_{BC} in I compared with III ($p_{I,III}=0.048*$). TP_{BD} was significantly larger in I compared with II and III ($p_{I,II}=0.036*$, $p_{I,III}=0.041*$), as well as TP_{DB} in I compared with II ($p_{I,II}=0.047*$).

Through paired T-test, we found that after playing game, in terms of MS-B's Occurrence, two of the groups had significant difference except one group (I: $p=0.000*$; II: $p=0.007*$; III: $p>0.05$) in comparison with the pre-gaming. In terms of MS-B's Coverage, all of the groups had significant difference (I: $p=0.002*$; II: $p=0.029*$; III: $p=0.043*$) compared with the pre-gaming. Regarding MS-D's Duration, two of the groups had no significant difference except one group (I: $p=0.009*$; II III: $p>0.05$) compared with the pre-gaming, which remained the same as the MS-D's Coverage (I: $p=0.004*$; II III: $p>0.05$). In terms of TP_{AC}, TP_{BC}, and TP_{DB}, all of the groups had no significant difference after the game ($p>0.05$) in comparison with the pre-gaming. In terms of TP_{BD}, two of the groups had no significant difference after the game except one group (I: $p=0.001*$; II III: $p>0.05$) compared with the pre-gaming. All the above microstate parameters of the subjects were consistently reduced after playing game, except for MS-D's Duration, TP_{BD}, and TP_{DB} (they were increased).

The above statement can be reflected in Fig. 3. Among the part of parameters with significant differences between groups (e.g., microstate B and D parameters), the post-gaming variation trend of II and III was the same as I, but not as large as I. II took the second place. We did not find a significant difference among the three groups in the resting EEG microstate parameters before the game, but found it after the game (e.g., microstate B and D parameters, TP_{AC}, TP_{BC}, TP_{BD}, TP_{DB}).

IV. DISCUSSION

There were no significant differences in EEG microstate parameters among the three groups before playing the game. However, in the resting-state EEG data measured again after playing game, there existed some significant differences in microstate B and D parameters among the three groups.

The change of the microstate parameters can be interpreted as stability or engagement of the neural activity of the network generating that the microstate topography and conversely also may be interpreted as a sign of an hypoactivity [37]. Some researchers have conducted simultaneous EEG-fMRI studies, in which the EEG microstate analysis method is used to analyze EEG data, and the generalized linear model (GLM) is employed to convolute the correlation between the four microstate diagrams and each voxel in the fMRI BOLD time series. As shown in the results, the four EEG microstates are spatially associated with the four resting state networks (RSN) in fMRI. Besides, they are related to the auditory network of speech processing (microstate A), the visual network of visual image processing (microstate B), the default mode network or the prominence network of subjective internal autonomic processing (microstate C), and the attention network of attention relocation (microstate D) [46]–[48]. Because most of the microstate studies use these four classical microstates, we also choose these four microstates for research and analysis. At present, the corresponding analysis can be conducted using microstate topographic maps. According to previous research, microstate B is related to the occipital cortex and microstate D is related to the right middle and superior frontal gyrus, the right superior parietal lobule and the right inferior parietal lobule [6], [23], [49].

Microstate B: Using fMRI, the researchers found that GD (group I) showed higher brain activation in the inferior occipital cortex induced by gaming-related cues than HC (group III) [50], [51]. After playing game, the metabolic activation of the occipital lobe was enhanced in the GD group and the HC, while the metabolism in the GD group was higher than that in the HC, presenting a different activation pattern of regional brain metabolism compared with the HC. This suggests that indulging in game may lead to changes in brain function during adolescence [31]. Similar studies concluded that after playing game, the functional connection (FC) of the occipital lobe in the GD group was significantly lower than that in the HC [32].

Microstate D: Some research results showed that the severity of GD was negatively correlated with the gray matter volume (GMV) of the right middle frontal gyrus (MFG), positively correlated with the GMV of the left caudate gyrus, and negatively associated with the FC of the left caudate gyrus and MFG [52], [53]. Gaming disorder is associated with the neuroanatomical changes of the right middle frontal lobe and the left caudate nucleus. These areas are important brain regions in reward and cognitive control processes. In addition, their structural and functional abnormalities are associated with other addictive behaviors, such as drug abuse and pathological gambling. After playing game, the dynamic FC between the left caudate gyrus and the right middle frontal gyrus in the GD was significantly lower than that in the RGU (group II), while the dynamic FC between the left triangular inferior frontal gyrus and the right middle frontal gyrus in the GD was obviously higher than that in the RGU [54]. When the GD was exposed to online game (game cues) stimulation, the right inferior parietal lobule and left caudate nucleus showed stronger signal activity than the HC [55]. Moreover, the activation of the right superior parietal lobule in the GD was stronger than that in the HC [56].

The above researches can contribute to understanding the significant changes of microstate B and D parameters in the GD after the game. Additionally, the significant difference in TP among three group aroused our interest. Generally, it can be assumed the presence of a direct interaction between two networks when inhibition or activation of regions belonging to one network causes effects on the activity of the other one. Compared with the other two groups, the TP from microstate A and B to C decreased, and the TP between microstate B and D increased in the GD. The results suggested that the brain FC between microstates A and B, and between A and

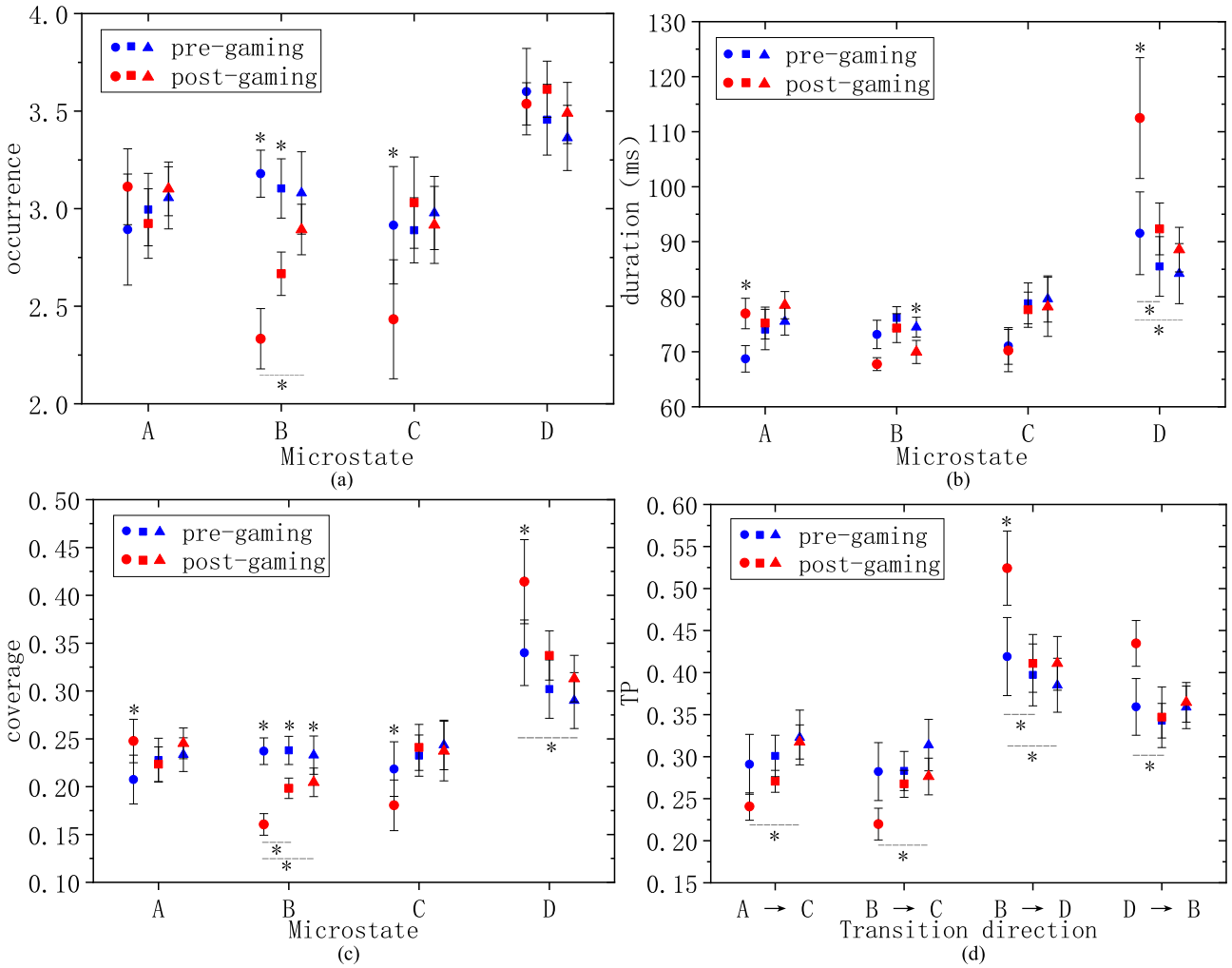

FIGURE 3. Microstate parameters (mean and standard error) in the pre-gaming, post-gaming, and difference between pre-gaming and post-gaming stimulation. The top stars of graphics indicate significant differences between pre-gaming and post-gaming, as assessed by paired t-test. The bottom stars of graphics indicate significant differences among groups, as assessed by one-way ANOVA. Group average statistics of the temporal microstate parameters: (a) mean duration, (b) occurrence, (c) time coverage, and (d) TP. Limited to space, the TP map only draws part of the data with differences between groups. (Blue represents pre-gaming, red represents post-gaming; the circle represents group I, the square represents group II, and the triangle represents group III.).

C was significantly weakened, and the connectivity between microstates B and D was significantly enhanced in the GD.

Microstate C is also associated with the default mode network (DMN), which exerts an important role in addiction [57]. DMN is a unique connecting area of the brain, which is activated in the resting state and inhibited in the task state [58]. The study revealed that compared with the HC, GD demonstrated that the resting-state FC between DMN-related regions was decreased [57], [59]. It might be that the sound stimulation and visual stimulation during the game have a great influence on the GD, inhibiting its DMN until a period of time after the game.

The reason accounting for the increase in the TP between microstates B and D may be that GD pay more attention to the game. Notably, visual stimulation plays a more dominant role in the game and can attract most of the players' attention. It should be pointed out that microstate B parameters of all groups have changed significantly after playing game. Therefore, so it can be inferred that the effect of visual stimulation on human brain area is extensive.

We have explained the abnormal changes in GD in detail. For RGU, the range of microstate parameters was basically between GD and HC, or closed to HC. There existed no significant difference in microstate parameters between RGU and HC. The possible reason was that according to the report of RGU, they did not feel guilty about playing games. They also said that the frequent use of games did not affect their study, daily life or work, and did not have a substantial effect on brain function or structure similar to that of GD. What needs to be added is that as far as the microstate parameters of GD were significantly different between groups, the corresponding post-gaming microstate parameters of all groups increase or decrease consistently. The obtained findings suggest that the effects of games on everyone's brain function

and structure may be similar, indulging in games may have a substantial impact on brain function or structure. Because addiction is a cumulative process, RGU may be between addicts and healthy controls with the possibility of developing into GD.

V. CONCLUSION

The above hypotheses only come from the relevant findings, because no previous studies have conducted causal investigations on the relationship between the microstates of players of different levels and the functional networks of the human brain. Currently, in the early stages of the microstate research of gaming disorder, we can only speculate on these results.

In order to explore the feasibility of EEG microstate parameters as markers of gaming addiction, we attempted to study the resting EEG in two states. One is the resting EEG before playing the game (similar to the resting state in the study of substance addiction) and the other state is after playing the game. What is not completely consistent with the researches of substance addiction is that we found no significant difference in EEG microstate parameters among the three groups before playing the game. However, there existed significant differences in some parameters (such as microstate B and D) after playing the game. The possible reason refers to that game addiction has less profound impact on the human brain than substance addiction, and it requires a certain degree of activation (such as playing the game) to show up in the microstate parameters.

Taken together, our data demonstrate that gaming behavior selectively inhibits or activates a certain brain region and reorganizes the overall brain activity described by EEG microstates. This approach can help better understand the organization of human brain networks and infer the causal relationship between different brain network activities. Moreover, our discoveries provide the first causal evidence of a microstate modification following gaming behavior interference, suggesting that microstates B and D are closely related to gaming behavior, and their parameters can be used as EEG markers for distinguishing gaming addiction. In addition, it could also be found that the impact of games on different populations is common, and non-addicts such as RGU have the possibility of turning into GD.

VI. LIMITATION

We only analyzed the resting-state EEG of 1 minute before and after playing the game. This should be improved in future experiments. And the eligible GD subjects were 12, then the other two groups also selected a similar number of people. The number of subjects will be increased in the course of further study.

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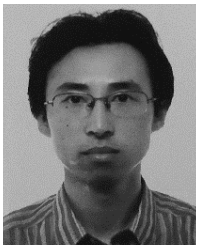

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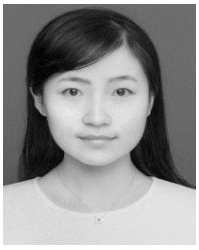

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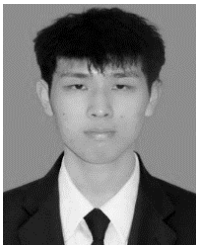

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