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The investigation on EEG characteristic parameters change when executing cognitive ability tasks under centrifuge G acceleration

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Abstract

Objectives: Flight cognitive ability is the core element of guaranteeing flight safety. This study attempts to explore the basic cognitive operation ability of pilots under overload environment, and provides reference for the research on the index screening and monitoring technology methods cognitive operation ability under centrifuge overload condition.

Methods: A specific cognitive operation ability task is designed, physiological signals such as electroencephalography (EEG) when performing cognitive ability tasks under human centrifuge overload condition are obtained, and the characteristic parameters changes are studied.

Results: When performing cognitive tasks, both the beta waves and the Theta/Beta Ratio (TBR) parameters in EEG show certain specific changes after the task starts and in the later stage the task.

Conclusions: Beta wave energy ratio and TBR parameter can better reflect the changes of pilot's cognition under overload environment, and the joint research of multiple frequency bands and multiple parameters helps to find the parameters and indicators with the potential to become the physiological monitoring index of pilot's cognitive operation capacity under overload condition more quickly and better. This study lays a foundation and provides a reference for the follow-up selection of physiological monitoring index of a pilot's cognitive operation ability and the research of monitoring technology on cognitive operation ability under overload condition.

Keywords: physiological monitoring; EEG; flight safety; aircraft operation; pilot cognition

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Introduction

Flight cognitive ability is the comprehensive embodiment of pilots' psychological quality, and is the core element of pilots successfully completing the flight and ensuring flight safety. Pilots should have good perception, attention, memory, spatial orientation, and manipulation abilities, which directly affect the combat effectiveness of aviation units [1]. Cognitive load is also important for general aviation [2].

At present, the basic cognitive ability testing for pilots mainly focuses on the field of psychological selection and identification of pilots on ground, and there have been no reports on its use in overload environment. The main reason is that there are many testing items and questions, and the required time is relatively long. However, the duration of overload during flight is mostly short, and it is impossible to synchronously implement the basic cognitive ability testing for pilots. Therefore, it may not be applicable under overload condition. In the last 20 or 30 years, advance in computer science has enabled to develop out devices that can accurately and precisely capture cognitive process. Among these technologies, eye tracking and ERP have been widely applied in the field of behavioral research, and both can facilitate the making models of cognitive process through the precise description of time process. At present, the main indicators for measuring and monitoring cognitive abilities include electroencephalography (EEG), eye tracking technology, and event related potential (ERP). 1. EEG measures the sum of neurosynaptic potential of synchronously discharging measured with very high temporal accuracy through electrodes placed on scalp [3]. Many scholars at home and abroad have studied the characteristics of EEG change during flight and under centrifuge G load, attempting to continuously explore the EEG change regularity under gravity acceleration and its simulation conditions [4–8]. 2. Due to that EEG represents the sum of a large amount of neural activity, it is difficult to isolate and identify the specific neurocognitive processes during continuous recording. To avoid this problem, researchers in the field of neuroscience have established and used a technique called Event Related Potential (ERP). ERP has a time resolution of milliseconds or even microseconds and is widely used in cognitive neuroscience [3, 9]. At present, ERP technology has been widely applied in neuroscience, visual, image processing, and cognitive science [10–13]. However, in the application process of ERP, in order to avoid eye electrical artifacts caused by excessive eye twitching or blinking, stimulus information is generally separated and presented separately, and participants are required to keep their eyes fixed on screen to avoid unnecessary eye movements. However, this brings new problems and difficulty, especially for complex tasks such as reading or visual scene perception. Therefore, ERP may not be suitable for the testing of pilots' complex cognitive tasks in high overload environment. 3. Eye tracking, also known as visual tracking technology, is a high-resolution method which can capture cognitive process [3, 14]. However, eye tracking technology is currently mostly used for ground testing and experimentation, and partial eye trackers are limited in their application under high load condition due to device structural style, wearing way, weight and other reasons. 4. Eye Fixation Related Potential (EFRP). EFRP is a method that combines eye tracking and traditional ERP technology to observe the processing corresponding to the fixation point event. The main advantage of EFRP over traditional ERP is that it provides a possibility to study cognitive mechanism in a more natural environment [3, 15, 16]. It can utilize the advantages of both eye movement and EEG technologies, compensate for their respective shortcoming, and not rely on experimental conditions such as complexity of stimulus and length of measurement time and so on, thereby more accurately revealing the richer cognitive processing process.

In this study, a specific cognitive operation ability task is designed under human centrifuge G load. The EEG characteristic parameters during executing cognitive task are studied to preliminarily filter physiological monitoring indicators that can be used to detect and train for pilots' cognitive operation ability under overload condition. This study provides a reference for the research on indicator filtering and monitoring techniques method of cognitive operation ability under centrifuge overload condition. There have been no relevant reports in domestic before.

Experimental methods

Experimental subjects

The experimental subjects are four volunteers, aged 19–20 years old. The subjects are clear about the experimental content and volunteer to participate. The experiment went through an ethical review process.

Experimental equipment

Human centrifuge: The AMST-HC-4E human centrifuge, which has a main arm with a length of 8.0 m. The front of the cabin is a spherical screen with a view field of 120° (horizontal) × 60° (vertical), using an independent projector to display cognitive ability testing and training tasks at the center of the subject's view field. The right front side of the seat in cabin is equipped with a Thrustmaster A-10C one handed joystick (side bar) for subject to perform cognitive ability testing and training tasks.

EEG acquisition equipment is a multi-channel EEG, integrated acquisition system from Beijing Zhongke Borui Company. This experiment uses 16 leads.

The design of experimental cognitive task

The experimental cognitive task adopts the "Motion Inference" project in "Pilots Cognitive Ability Testing and Training System" developed by Shanghai Diyi Technology Co., Ltd. This task is used to study the impact of +Gz on motion inference perception of subject, focusing on key tasks such as collision avoidance, missile avoidance, overall timing ability, multitasking treatment, and formation combat and so on, and involving key cognitive processes such as slow motion inference, fast motion inference, speed perception, simple decision-making, and tracking and so on. The task is presented as the following: a semi-circular motion path, a light spot moving along the semi-circular path, and a target line are first displayed on the screen in front of the pilot. The light spot will move at different speeds, and the target line will be randomly positioned at a certain point on the motion path. The light spot will disappear without any prompts after moving along a semi-circular path for 1/3 arc segment, and synchronously four letters will randomly appear in the lower middle position of the screen. Task execution process: After the task begins, the light spot moves along a semi-circular path from its initial position and disappears after passing through 1/3 arc segment. At the same time, random letters appear below the screen, the subject first judges whether there are vowel letters in them, and responds by pressing the corresponding button on the joystick; Then estimating that when the light spot which moves at a constant rate reaches the target line, the subject presses the button on the joystick. At the end of this task, a new task will begin immediately. Tasks can be executed with a choice of either a "total task limit" or a "time limit". In this experiment, the set total number of tasks is limited to 30 during static testing, and the set task time is limited to 45 s during overload running.

The design of centrifuge running curve

The +Gz exposure on centrifuge adopts a trapezoidal curve pattern, and each exposure starts from a baseline acceleration of +1.4 Gz, increases at a rate of 1G/s to a plateau period lasting for 15 s, and then decreases at a rate of 1G/s to the baseline. The subject wears KH-8 anti load clothing. The set acceleration curve is shown in Figure 1, in which the G value in platform period is 3G and the plateau period is 15 s.

The implementing methods of cognitive tasks

Firstly, baseline data are collected from subjects performing cognitive ability tasks testing under static condition on ground, including 30 performing inference tasks and 12 short-term memory tasks. Then overload exposures of +5.0 Gz/15 s and +6.0 Gz/15 s are performed respectively. The curve is similar to that in Figure 1, except that the platform period G value is set to 5G and 6G respectively. Cognitive ability task testing is conducted simultaneously with each exposure, starting approximately 5 s (motion inference task) or 10 s (short-term memory task) before +Gz load increasing after each centrifuge running at baseline (+1.4 Gz), and continuing until after the acceleration returns to the baseline Gz level and the task is completed. The interval time between +Gz exposures is 1 min, during which the subject relaxes and rests. During the exposure test, the subjects' ear pulse wave, electrocardiograms (ECG), and subject's chief complaint are monitored. The endpoint of endurance is determined by loss of peripheral lights vision (PLL) or amplitude of ear pulse decreasing more than 75 %, or the subject cannot continue to insist on the experiment due to fatigue, tenderness, and other reasons. Other emergency shutdown indicators include technical malfunctions, heart rate of subject is >200 bpm, or appearing severe arrhythmia.

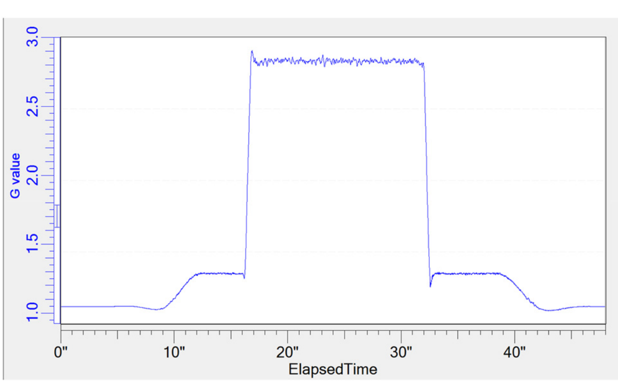

Figure 1: The acceleration graph when G value in platform period is 3G.

During experiment, the completion status of the subjects' tasks, includes reaction time, accuracy, and other indicators which are automatically recorded by "Pilots Cognitive Ability Testing and Training System"; EEG is recorded by a multi-channel EEG acquisition system (Zhongke borui technology co., ltd (Beijing)). The multi-channel EEG acquisition system includes an electrode cap, a signal acquisition module, and a computer terminal. EEG in this experiment uses 16 leads. EEG data are preprocessed and then subsequently analyzed. This study focuses on the obtained EEG signals.

EEG data analysis in the study all uses EEG signal collected from the frontal single channel Fp1 electrode. Fp1 and Fp2 are electrode positions located on the left and right sides of the frontal lobe in EEG detection, involving advanced cognitive processes such as attention, decision-making, and working memory and so on. The frontal lobe is closely related to emotional processing and is commonly used in research on emotion regulation, cognitive control, and autonomic nervous system regulation and so on. According to the functional division of brain regions, the acquisition based on EEG signal at frontal lobe can be used to better assess the mental state of human body, such as drowsiness, fatigue, lack of concentration, and memory decline and so on. Fp1 and Fp2 are symmetrical. Considering that the EEG reflected by Fp1 lead is more closely related to cognitive function such as logical thinking and analysis and so on, while the EEG reflected by Fp2 lead is more closely related to cognitive function such as imaginal thinking and emotional expression and so on, more concerns should be put on the cognitive abilities such as logical thinking, judgment and analysis of pilots, so the study of Fp1 lead is focused on.

The denoising treatment of EEG

The EEG signals of Fp1 and Fp2 leads are susceptible to interference from blinking, EMG (electromyography), body movement, power sources, etc., and require special methods for preprocessing to remove signals such as EOG (electrooculogram) activity and so on. In this study, subject inevitably becomes nervous and engaged in certain confrontational movements when experiencing +GZ load exposure in cabin, thus EEG also is influenced by EMG, which is mainly concentrated in the frequency range of 35.8–51 Hz; EOG is difficult to remove as it may be mixed in multiple frequency bands of EEG, which can easily lead to the loss of useful information during the elimination process. Therefore, based on experimental experience, signals within the 0.5~1 Hz frequency band can be mainly removed; The frequency of alternating current is concentrated around

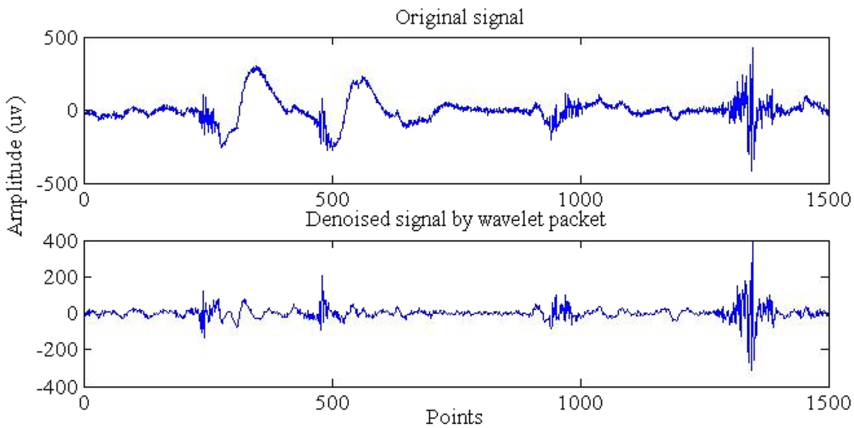

Figure 2: The comparison graph of EEG filtering effect during a task.

50 Hz; Electrode fixing and baseline drifting can easily form low-frequency slow waves below 0.8 and 0.2 Hz; The interference caused by the rotation of centrifuge cannot be ignored. According to the maximum achievable G value in the experiment, and the radius of centrifuge main arm, through the conversion formula of centripetal acceleration, it can be calculated that the interference of the centrifuge rotation on the signal is mainly below 0.5 Hz frequency. By using wavelet packet transformation to decompose and reconstruct signals, useful frequency bands of EEG signal can be extracted, and interference signals from various frequency bands can be filtered out. A band-pass filter is designed by using wavelet packet transform method and appropriate parameter thresholds are selected to filter EEG. Based on the above interference frequency bands, the lower limit of filter is around 1 Hz and the upper limit is around 35 Hz. According to the sampling frequency and the characteristics of dynamic EEG signal, the Daubechies 5 wavelet is selected to perform n-layer decomposition for the original signal. The minimum resolution can be estimated using the following equation, $\Delta f = \frac{1}{2^n} * \frac{f_s}{2}$. When performing six-layer decomposition, the minimum resolution is 1 Hz, and when performing seven-layer decomposition, the minimum resolution is 0.5 Hz, where f_s is the sampling frequency. The following Figure 2 shows the comparison graph of the Fp1 lead of a subject's EEG before and after filtering during a task. The selected data segment has obvious interference of EOG signal. From the figure, it can be seen that after filtering, signals such as EOG and electromagnetic interference and so on have been effectively filtered out.

Experimental results

Each subject experiences overload exposures of +5.0 Gz/15 s and +6.0 Gz/15 s. When +5.0 Gz/15 s or +6.0 Gz/15 s exposure is performed every time, a cognitive ability task testing is conducted at the same time. EEG data are obtained during the whole centrifuge running. The original EEG data are preprocessed to remove EOG, baseline drift and other interferences, and the denoised EEG signal is obtained. The denoised EEG signal is made time-domain and frequency-domain analysis. EEG time-domain graphs are drawn out, and it can be seen that the change of beta wave is relatively obvious. The energy spectrums of each band in frequency domain are calculated and drawn out. It is found that the change of beta wave is relatively significant, and beta wave is usually correlated with human tension and mental high concentration. Therefore, the energy proportion of beta wave is focused on. The energy proportion curves of beta wave of four subjects are drawn and analyzed.

In cognition, attention indicators are usually represented by the parameter theta/beta ratio (TBR). The concentration degree of subject's attention during task experiments is judged by using TBR parameter. Generally, the lower the value, the more focused attention is. Similarly, TBR curves of four subjects are drawn and analyzed.

The energy proportion analysis of beta wave

The signal energy of each band is calculated from the overall power spectrum density of EEG signal, and the energy spectrums of each band for four subjects are drawn. The energy proportion of beta wave is focused on and analyze. Here "the energy proportion" means relative power, and it refers to the proportion of the energy of beta wave in the total energy of all waves. It is expressed as a percentage. The following Figures 3 and 4 are the energy proportion curves of beta wave of two subjects during executing tasks.

From the figures, it can be roughly seen that after task starts, beta wave increases, and the proportion of beta wave

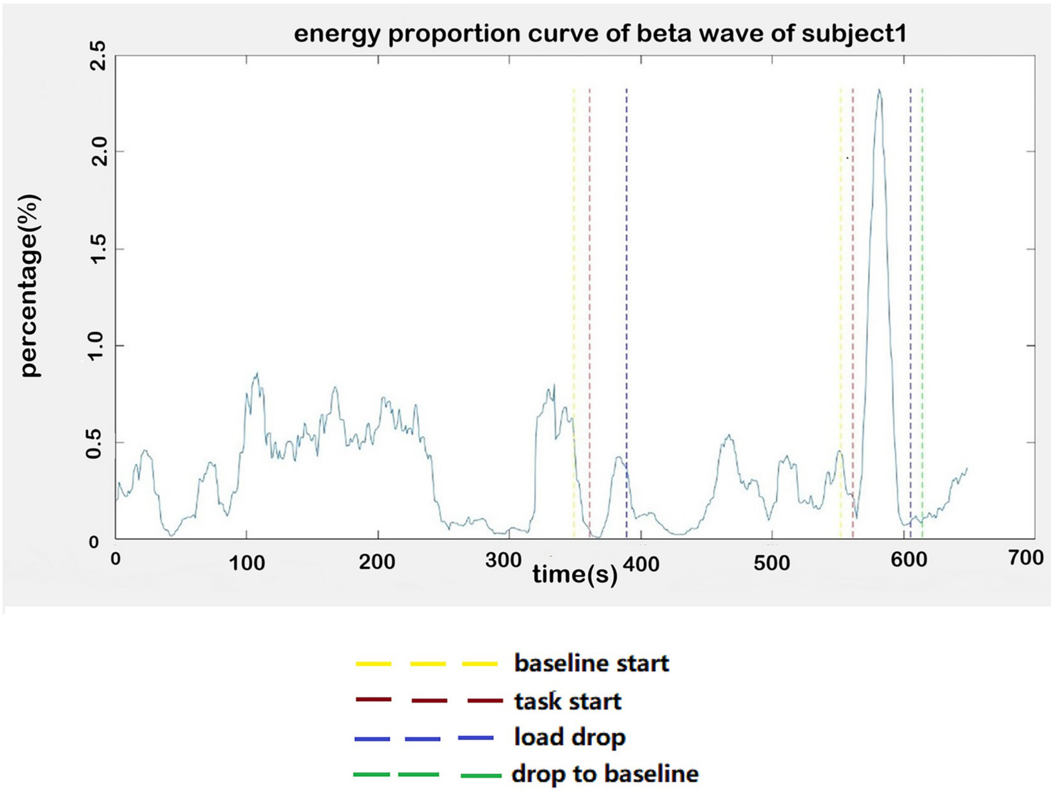

Figure 3: The energy proportion curve of beta wave of subject 1.

increases occupying the main advantage. When load reaches its peak, the energy of beta wave gradually weakens, and in the later stage, beta wave decreases, and the energy of slow waves begins to increase. There is a sudden change position in the curve in the figure, and it is suspected that data are corrupted or are disturbed.

The parameters analysis of theta/beta ratio (TBR)

The TBR parameter is usually used to determine the concentration degree of subject's attention during task experiments. TBR is the ratio between the powers of theta frequency band and beta frequency band. Through this ratio, the relative intensity of EEG activity in different frequency bands can be reflected, which helps to analyze the electrical activity characteristics of brain in different functional states. TBR curves graphs of four subjects are made out. The following Figure 5 and 6 show the energy proportion curves graphs of beta wave of two subjects during task execution.

From the graphs, it can be seen that TBR value has decreasing of different degrees after task starts, and then rises. TBR curves of subject 1 are opposite to the curves of the other subjects, and it is suspected that the subject's data are damaged or disturbed.

Discussion

The change analysis of characteristic parameters of EEG in frequency domain

Both in time domain and frequency domain, the changes in the beta waves are considerable. Beta wave is usually associated with tension and mental high concentration of human, and their performance in time-frequency domain is basically consistent, that is during task period, the energy proportion of beta frequency band increases, and beta wave dominates. Numerous studies have shown that the existing technological methods for monitoring concentration mental state are mainly related to the specific frequency bands in EEG. The energy proportion of beta wave may better reflect

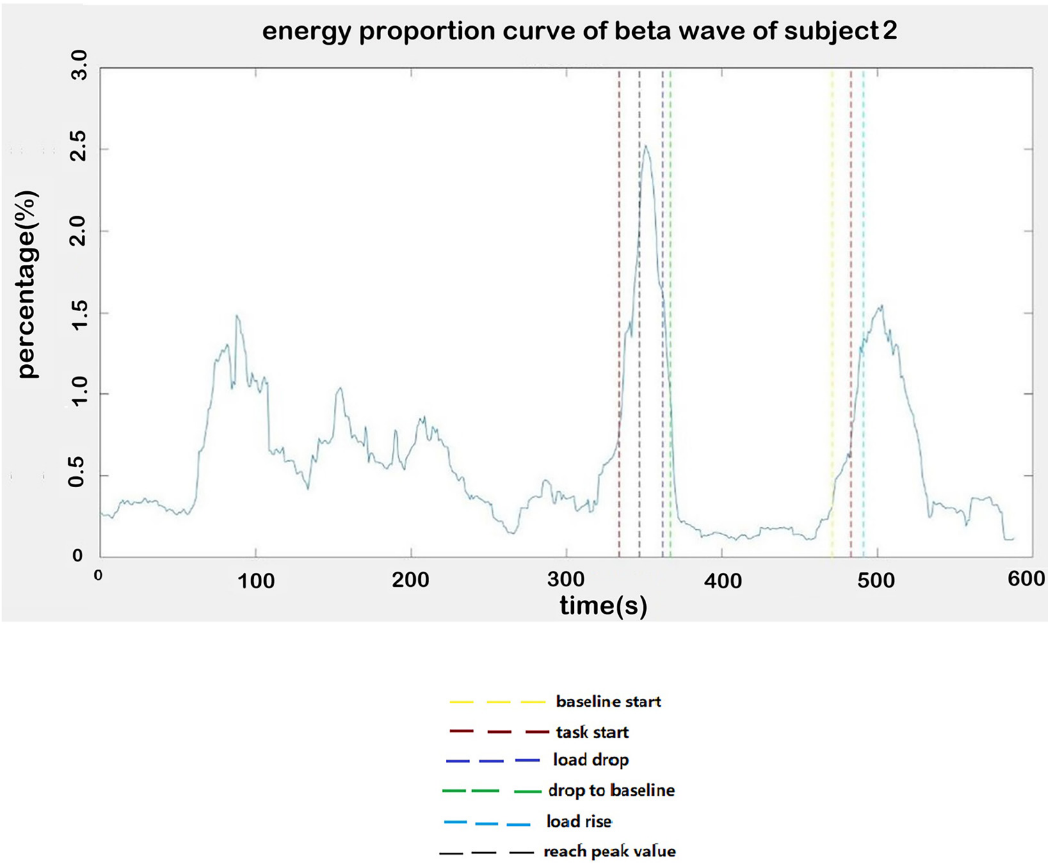

Figure 4: The energy proportion curve of beta wave of subject 2.

the change state of the subject's cognitive, and beta wave can be focused on.

TBR, that is theta/beta ratio is used to judge the concentration degree of subject's attention during task experiments. Generally, the lower the value, the more focused the attention is. Except for subject 1, the performance of this parameter of other subjects is basically consistent, that is, TBR value has decreasing of different degrees after task starts and then rises, explaining that after task starts, the subject's attention is not focused, begins to disperse, and the attention level decreases. The study also analyzes the permutation entropy parameter, which shows that during task period, the permutation entropy value increases, but with the time of loading action increases, the permutation entropy value decreases and the brain activity degree weakens. The variation characteristics shown by TBR are consistent with that shown by permutation entropy. TBR can better illustrate the cognitive change state under specific tasks from the perspective of concentration. A large number of studies have investigated the changes of energy ratios between beta, alpha, and different frequency bands induced by attention. Overall, it is believed that an increase of activities of high-frequency bands such as beta wave is a kind of indicator of attention arousal, and there are also studies showing that the energy ratio of theta to beta, as well as a the energy decreasing of alpha and theta waves, also indicate a higher level of concentration degree. TBR only provides an explanation of cognition from the perspective of concentration. To fully understand the change state of cognition, it is necessary to analyze together it in conjunction with other parameters.

What needs to be improved in the research

The detailed research of beta wave should be strengthened. The research result indicates that the energy proportion of beta wave can indeed reflect the change state of subject's cognitive well. Beta rhythm (13–25 Hz) indicates that a person is in a state of "alertness", and the transition of this rhythm to a slow wave foretells and indicates that the person's alertness is undergoing changes [7]. Chen et al. found in the lower body negative pressure experiment that power percentage index of the β 2 frequency band suddenly

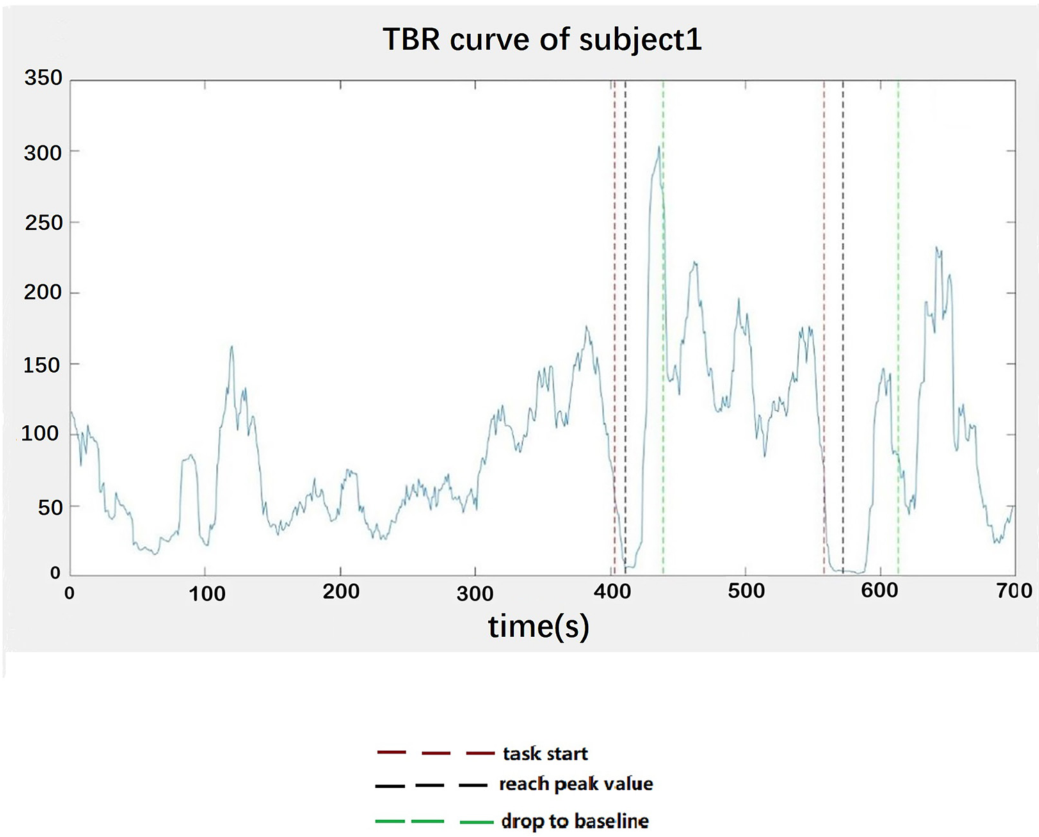

Figure 5: TBR curve graph of subject 1.

decreased at the 1 min moment before syncope [5, 8]. In these two papers, β 1 refers to the frequency range of 13~19.8 Hz; β 2 refers to the frequency range of 20–29.8 Hz. Therefore, β2 wave may better reflect the change characteristics of β wave, β wave can further be refined and the feature extraction and analysis of β 2 wave can be strengthened.

Attaching importance to α wave, the joint research and application of α wave and β wave should be strengthened. According to the relevant contents in chapter 3 -'Classification and description of EEG" of the book "Clinical Electroencephalogram" [17] and in chapter 4-"Electrotopographic Mapping of Normal Human Brain" of the book "Modern Practical Brain Electrical Topography" [18], the rhythm of alpha wave in EEG is (8–13 Hz), which is between the awake and drowsy states of human, and is more common in the state of awake and closed eye. Alpha wave is one of the main components of spontaneous EEG and is the component with most prominent feature in rhythmic EEG. The percentage index of alpha wave, as a physiological indicator reflecting concentrated attention, has a theoretical basis and factual basis for judging human movement and behavioral abilities. The higher the degree of alpha is suppressed, the more focused the attention is, indicating that the person's level of wakefulness at that time is higher. Therefore, it is necessary to strengthen the attention and research on alpha wave. Recently, some scholars have extracted valuable feature parameters through the analysis method of periodogram parameters, and found that some characteristics which are simultaneously showed in advance by alpha and beta frequency bands of comprehensive parameter R corresponding to ear pulse leveling, as well as some specific manifestations of R parameter of beta frequency band, may has significance for the early warning of syncope caused by +Gz load in the future [6]. Therefore, the combined application of alpha and beta waves may excavate more EEG feature changes related to concentration. The joint study of alpha and beta waves should be strengthened to investigate the changes of EEG parameters when performing cognitive ability tasks under G load action.

The research and validation of multiple parameters. Compared to other parameters, TBR parameter performs well, and the changes of parameters such as permutation entropy and Beta ratio (RBR) and so on can be continued to

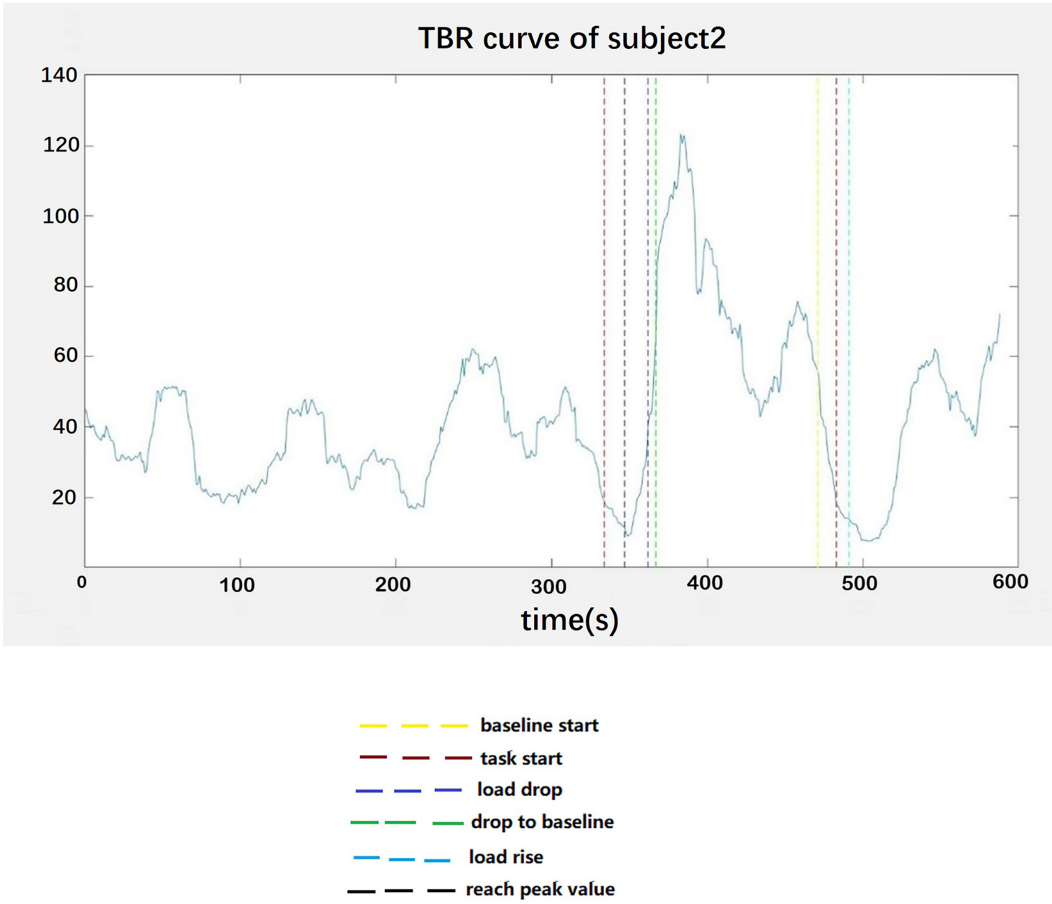

Figure 6: TBR curve graph of subject 2.

make research and calculation later. By comparing change of each parameter and mutual verifying change characteristic of each parameter, the better parameters and indicators that have the potential to become physiological monitoring indicators for pilot's cognitive operation ability under overload condition can be gradually found. In further classification methods such as decision trees and so on can be further applied to test and validate parameters such as TBR and so on in the future.

The number of samples is limited. The biggest limitation of this study is the number of subjects and the number of samples are limited. There are four subjects in the study, and in some tasks, the result of subject 1 is always opposite to that of other subjects, and it is suspected to be caused by data damage or artifacts interference. Therefore, it is excluded during analysis to make the amount of data available less. In subsequently, the number of subjects should be increased to further expand the sample amount of experiments.

Conclusions

This paper first explains the necessity of studying cognitive ability of human under centrifuge overload condition. EEG electrophysiological signal of subject performing specific cognitive tasks under centrifuge overload condition is obtained, with a focus on studying the two parameters which are energy proportion of beta wave and Theta/Beta Ratio (TBR) in frequency domain. The result indicates that after task begins, the energy of beta wave in each band increases and the energy proportion of band energy increases, which can be focused on. The change of TBR parameter can better reflect the cognitive ability of brain, and this indicator has the certain potential to become a physiological monitoring indicator of pilot's cognitive operation ability under overload condition. At the same time, this study has shortcomings and needs to be improved, such as strengthening the feature extraction of β2 waves in β wave; At the same time, attention should be paid to alpha wave, and the joint research and application of alpha wave and beta wave should be strengthened; In addition to TBR parameter, further research can be conducted on other parameters such as permutation entropy and beta ratio (RBR) and other parameters, to form mutual comparisons and verifications of their changes; The biggest limitation of this study is that the numbers of subjects and samples are limited, which can be further supplemented and expanded in the future. This study provides important reference basis for the screening of physiological monitoring indicators for the detection and training of pilot's cognitive operation ability under centrifuge overload condition, and for the method research of monitoring techniques for cognitive operation ability under centrifuge overload condition, and has certain reference significance.

Research ethics: The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The experiment was approved by the Ethic Review Committee of this working organization, and due to confidentiality reasons, the relevant documents cannot be provided.
Informed consent: Not applicable.
Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.
Use of Large Language Models, AI and Machine Learning Tools: None declared.
Conflict of interest: The authors state no conflict of interest.
Research funding: None declared.
Data availability: Not applicable.

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