Attention State Related EEG Spectrum and Pupil Size in Vigilance Task

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Abstract. Objectively recognizing Attention State is a particularly important task to ensure vigilance decrement in Vigilance Task. The aim of this study was to develop a vigilance task system using Electroencephalogram (EEG) signals to identify four kinds of Attention State including Thinking Otherthing (TO), Sleepy(S), Attention Outside (AO), and Attention to Screen (ATS). Simultaneously, Pupil dimension was recorded as reference. We approached this objective by firstly investigating the relevant EEG frequency band followed by deciding the appropriate feature extraction method. Two features were considered namely: 1. Wavelet Energy Percent, and 2. Wavelet Cosine Similarity. The results presented in this study indicated that wavelet energy percent extracted from alpha, beta, delta and theta bands seem to provide the necessary information for describing the aforementioned Attention State. Using the Wavelet Cosine Similarity (Dataset for attention state Analysis using electroencephalogram, subjective valuing and Vigilance Signals), our proposed method achieved a significant sensitivity and specificity. Deviation of pupil size also reflected the four kinds of attention state.

Introduction

Pupil size¹ is often used to infer central processes, including attention, memory, and emotion. The mathematical description of pupil responses serves as a prerequisite to refining their relation to behavioral and brain indices of cognitive processes. Pilots with better situational awareness² performance exhibited a smaller pupil size during the operational phase of lock on while pursuing a dynamic target. Attentional effort³ relates to the allocation of limited-capacity attentional resources to meet current task demands and involves the activation of top-down attentional systems in the brain, it is thought to modulate the operations of the brain's attentional systems. Eye movements and the pupillary light response⁴ maximize visual acuity, stabilize visual input, and selectively filter visual information as it enters the eye. Event-related responses⁵ to unpleasant images significantly inhibited the rate of microsaccade appearance and altered pupil size. Daytime variations in the pupillary unrest index⁶ in healthy normal subjects were found to be positively correlated with the level of alertness. Pupil change⁷ was related to familiarity with the stimulus slide and the relative pupil response changed as subjects gained experience with the stimulus material.
The eye's pupils constrict (shrink) in brightness and dilate (expand) in darkness. Here, we review recent studies that have dramatically changed this view: The light response depends not only on a stimulus's brightness but also on whether you are aware of the stimulus, whether you are paying attention to it, and even whether you are thinking about it.

The overall amplitude of pupil dilation during decision formation was bigger before yes than no choices, irrespective of the physical presence of the target signal, the magnitude of this pupil choice effect (yes > no) reflected the individual criterion: it was strongest in conservative subjects choosing yes against their bias. We conclude that the central neuromodulatory systems controlling pupil size are continuously engaged during decision formation in a way that reveals how the upcoming choice relates to the decision maker's attitude. Changes in brain state seem to interact with biased decision making in the face of uncertainty. Lexical search and sentence integration, and the more general issue of depths of processing.

Global Integration of Functional Connectivity in Lower Alpha Band. Alpha synchronization reflects changes in the excitability of populations of neurons whose receptive fields match the locus of attention. This is consistent with the hypothesis that alpha oscillations reflect the neural mechanisms by which top-down control of attention biases information processing and modulate the activity of neurons in visual cortex. Alpha-band neural oscillations periodically transmit prior evidence to visual cortex, changing the baseline from which evidence accumulation begins.

Increased beta-band phase alignment during attentional engagement early during the task was restricted to inferior and lateral prefrontal cortex, but with sustained attention it extended to long-range phase synchronization and included superior prefrontal areas. The reduction in the number of prominent features improves the sleep-onset classification speed in the support vector machine (SVM) and results in a high sleep-onset recognition rate. An increase in the beta-frequency band (13-25 Hz) power in the right inferior and middle frontal gyri was caused by the mental fatigue. The increase in the beta-frequency band power in the right middle frontal gyrus was negatively associated with the self-reported level of mental stress and was positively associated with those of boredom and sleepiness.

Both attentional processes simultaneously modulated the power of anticipatory delta- and beta-band oscillations, as well as delta-band phase coherence. Modulations in sensory cortices reflected intersensory attention, indicative of modality-specific gating mechanisms. Modulations in motor and partly in somatosensory cortex reflected temporal orienting, indicative of a supramodal preparatory mechanism. We found no evidence for interactions between intersensory attention and temporal orienting, suggesting that these two mechanisms act in parallel and largely independent of each other in sensory and motor cortices.

The research demonstrate some potential indicators for mental fatigue detection and evaluation, which can be applied in the future development of countermeasures to fatigue. In a task of intermodal attention there is a larger neural response at the beat frequency when subjects attend to a musical stimulus than when they ignore the auditory signal and instead focus on a visual one. Spindle waves are adequately sensitive, however, to noxious stimuli: under surgical anaesthesia they disappear when noxious stimuli are applied, and reappear when adequate analgesia is obtained. A new hypothesis,
that individuals may use the same idiosyncratic sets of areas, at least by their fraction of activity in the sub-delta and beta range, in various non-sensory-motor forms of conscious activities, is a corollary of the discussed variability.

Frontal intermittent rhythmic delta activity has long been considered to be an abnormal variant in the electroencephalogram (EEG) among older adults. Prior work also indicates a predominance of slow wave EEG activity among patients with dementia. However, instability of state control occurring with aging generally and among many neurodegenerative diseases raises the possibility that FIRDA might represent the intrusion of sleep related elements of the EEG into the waking state.

High target likelihood, compared with low likelihood, enhanced delta oscillations more strongly as measured by evoked power and intertrial coherence. Moreover, delta phase modulated detection rates for probable targets. The delta frequency range corresponds with half-a-period to the target occurrence window and therefore suggests that low-frequency phase reset is engaged to produce a long window of high excitability when event timing is uncertain within a restricted temporal window.

A stronger delta-beta coupling at parietal sites was associated with higher self-reported AC. However, no significant associations were found between executive control network functioning and the EEG ratio or coupling measures. Strong modulations of phase locking and weak modulations of single-trial power suggest that entrainment was primarily driven by phase-alignment of ongoing oscillatory activity.

The amount of theta activity was significantly greater for narcoleptic and obstructive sleep apnea subjects than that for controls.

Theta and Alpha Band Modulations Reflect Error-Related Adjustments in the Auditory Condensation Task. Theta and alpha-band oscillations serve dissociable roles: Prior to stimulus processing, the cortex might suppress ongoing processing in the nucleus accumbens by modulating alpha-band activity. Subsequently, upon stimulus presentation, theta oscillations might facilitate the active exchange of stimulus information from the nucleus accumbens to the cortex.

**Material and Methods**

**Participants**

Ten healthy right-handed college students (8 females and 2 males) from one university served as subjects after giving informed consent. Their mean age was 19 years, ranging in age from 18 to 20 years. Prior to the study, all of the participants were reportedly with normal or correct-to-normal vision, no neurological problems. No training in advance.

**Material and Designs**

Vigilance task designed by simulating Mackworth’s Rader Task of “Clock Test” based on signal detection theory, to let the participant monitoring the clockwise second hand moving, the second hand moves one space at a time, when the second hand move two spaces found out, it’s as signal, the participant had been requested “click the left mouse button”. The software automatically generates a new random sequence of signal to avoid sequence effects before 8-52 seconds at each try. The experiment lasted 80 minutes. Participants were required to keep track of the analog clock second hand beating, by a computer program automatic tracking and recording the reaction, reaction time, leak
inspection and alarm. And synchronously the brain EEG and eye movement were recorded by recorder software.

**EEG Data Extraction**

Sixteen-channel EEG readings were captured from the frontal, central, parietal, and occipital (FP1, FP2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5 and T6; Fig.1) regions. All electrodes were referred to linked ears. The data were recorded using a sampling rate of 200 Hz with a frequency band of 0.03 to 30 Hz. The impedance of the recording electrodes was always below 5 kΩ. EEGs are preprocessed with a Butterworth bandpass filter 15, and features are subsequently extracted from the filtered EEG signals by employing the wavelet-packet-transform (WPT) method to categorize the signals into four frequency bands: alpha, beta, theta, and delta. A mutual information technique selects the most descriptive features for further classification.

**Subjective Valuing**

Subjective valuing included four attention states: Attention to Screen (ATS), Attention Outside (AO), Thinking Others (TO) and Sleepy (S), were implemented while signal appeared in two seconds, evaluation of the pop-up interface accompanied by the monitor task based on time series, and prompts the instructions, made by the trial of mouse clicks to select the above four kinds of Attention State a few seconds ago. The evaluation methods can accurately reflect and record to be tried in a timely manner the Attention State in monitoring operations.

**Data Analysis**

Performance of monitoring (behavior), we used the average detection rate of signal (hit rate: HR) and hit reaction time (RT).

Eye movement rating used the pupil diameter and the fixation point on the screen position as index.

Acquisition of EEG signals, before the 2s of and at signal appearing, 1s fragments of the original signal, using band-pass filters filtering out 8 bands: δ (0.01-4Hz), Theta (4.01-8Hz), Alpha 1 (8.01-10Hz), alpha 2 (10.01-13Hz), Beta 1 (13.01-20Hz), Beta 2 (20.01-30Hz), Alpha (8.01-13Hz), beta (13.01-30Hz), 1. calculated each band's direct power to calculate the share of each band segment in full band (energy); 2. calculated cosine similarity of EEG band and the original waveform.

Final merged data using Spss13.0 software for statistical testing and analysis.

**Results**

**The Impact of Attention State on the Hit Rate, Pupil Size and Reaction Time**

Attention state to use subjective evaluation sheet prepared in analog control operation software, along with the signal Alerting also likely stimulus-response evaluation interfaces allow experimental evaluation, including: pay attention to the screen, the screen outside, to think of other things and sleep attack (sleepy).

Attention in the monitoring task has a significant impact on hit rate, F=276.174, p<0.01, pay attention to the screen(ATS) has the highest hit rate (0.893), sleepy(S) lowest hit rate (0.400), attention turned to other places (AO)(0.533) or think other things(TO)(0.703) reduces hit rate performance, as shown in table 1.
Attention orientation has significant effects on reaction time performance, F=336.318, p<0.01, pay attention to the screen (ATS) when the shortest RT (904.916 MS), the longest doze (Sleepy(S)) response (1585.000 MS), attention turned to other places (AO) (1499.333 MS) or think other things (TO) (1220.921 MS) will reduce the reaction time performance, as shown in table 1.

Attention has a significant impact on pupil size, left eye: F=81.635, p<0.01; right: F=71.424, p<0.01, pay attention to screen (ATS) pupil’s biggest (1.592mm of the left eye, right eye 1.593mm), at other places (AO) right eye pupil Max (1.697) and full episodes or doze off (S) pupils least (1.031 mm, 1.183 mm), Narrowing of the pupil when you think (TO) (1.380mm of the left eye, right eye 1.338mm), pay attention to the screen (ATS) and see the pupils while elsewhere (AO) than thinking others (TO) or sleep attacks (S), see table 1.

Table 1. ANOVA of Attention State for Hit, RT and Pupil Dimensions.

<table>
<thead>
<tr>
<th>Attention State</th>
<th>N</th>
<th>HR</th>
<th>RT</th>
<th>DLP</th>
<th>DRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TO (Thinking Others)</td>
<td>994</td>
<td>0.703</td>
<td>1220.921</td>
<td>1.380</td>
<td>1.338</td>
</tr>
<tr>
<td>S (Sleepy)</td>
<td>300</td>
<td>0.400</td>
<td>1585.000</td>
<td>1.031</td>
<td>1.185</td>
</tr>
<tr>
<td>AO (Attention Outside)</td>
<td>300</td>
<td>0.533</td>
<td>1499.333</td>
<td>1.555</td>
<td>1.697</td>
</tr>
<tr>
<td>ATS (Attention to Screen)</td>
<td>3728</td>
<td>0.893</td>
<td>904.916</td>
<td>1.592</td>
<td>1.593</td>
</tr>
<tr>
<td>F</td>
<td>276.176</td>
<td>336.138</td>
<td>81.653</td>
<td>71.424</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

* HR (Hit Ratio), RT (Reaction Time), DLP (Dimension of Left Pupil), DRP (Dimension of Right Pupil).

Attention Effects on EEG Spectrum Subband Energy Ratio and Waveform Similarity

Table 2. ANOVA of Attention State for EEG Spectral Sub bands Energy Ratio

<table>
<thead>
<tr>
<th>Attention State/ANAVO</th>
<th>Delta</th>
<th>Theta</th>
<th>Alpha_1</th>
<th>Alpha_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>TO</td>
<td>994</td>
<td>0.439</td>
<td>0.163</td>
<td>0.188</td>
</tr>
<tr>
<td>S</td>
<td>300</td>
<td>0.480</td>
<td>0.163</td>
<td>0.191</td>
</tr>
<tr>
<td>AO</td>
<td>300</td>
<td>0.480</td>
<td>0.172</td>
<td>0.177</td>
</tr>
<tr>
<td>ATS</td>
<td>3728</td>
<td>0.410</td>
<td>0.156</td>
<td>0.216</td>
</tr>
<tr>
<td>F</td>
<td>37.747</td>
<td>32.041</td>
<td>27.561</td>
<td>21.951</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attention State/ANAVO</th>
<th>Beta_1</th>
<th>Beta_2</th>
<th>Alpha</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>TO</td>
<td>994</td>
<td>0.042</td>
<td>0.040</td>
<td>0.022</td>
</tr>
<tr>
<td>S</td>
<td>300</td>
<td>0.029</td>
<td>0.024</td>
<td>0.012</td>
</tr>
<tr>
<td>AO</td>
<td>300</td>
<td>0.037</td>
<td>0.037</td>
<td>0.014</td>
</tr>
<tr>
<td>ATS</td>
<td>3728</td>
<td>0.046</td>
<td>0.036</td>
<td>0.023</td>
</tr>
<tr>
<td>F</td>
<td>23.936</td>
<td>16.888</td>
<td>35.985</td>
<td>25.142</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Analysis of variance found 4 corresponding attention paragraph 8-bands energy ratios are significantly different. Show that attention state has significant effects on EEG.
spectrum subband energy ratio. Attention state on Delta waves (0.03~4Hz) of energy ratio has a significant impact, F=37.747, p<0.01, pay attention to screen (ATS) the smallest Delta energy ratio (0.410). Rest and sleep onset (S, 0.480). As shown in table 2.

Attention state on the brain EEG spectra Theta (4.01~8Hz) band energy ratio has a significant impact, F=32.041, p<0.01, pay attention to the screen (ATS) the smallest proportion (0.216). Attention outside (AO) the minimum (0.177). Attention state on brain EEG spectra of Alpha 1 (8.01~10Hz) energy ratio has a significant impact, F=27.561, p<0.01, pay attention to the screen (ATS) the largest proportion (0.029). Attention outside(AO) the minimum (0.018). Attention state on brain electrical power spectra of α 2 wave (10.01~13Hz) energy ratio has a significant impact, F=21.951, p<0.01, pay attention to the screen(ATS) the largest proportion (0.040). Attention outside (AO) the minimum (0.025). Attention state on EEG spectrum Beta 1 (13.01~20Hz) energy ratio has a significant impact, F=23.936, p<0.01, pay attention to the screen(ATS) the largest proportion (0.046). The minimum the sleep attack(S) (0.029). Attention state on brain EEG Beta 2 (20.01~30Hz) energy ratio has a significant impact, F=16.888, p<0.01, pay attention to the screen (ATS) the largest proportion (0.023). Minimum of a sleep attack (0.012).

Attention to the tendency of power spectrum of EEG alpha waves (8.01~13Hz) frequency band energy ratio has a significant impact, F=35.985, p<0.01, pay attention to the screen the largest proportion (0.091). Attention outside (AO) the minimum (0.059). Attention state on brain EEG spectra beta waves (13.01~30Hz) energy ratio has a significant impact, F=25.142, p<0.01, pay attention to the screen (ATS) the largest proportion (0.074). Minimum of a sleep attack (0.044). TO beta wave energy ratio and ATS close to the proportion, and significant differences from sleep attack(S) and AO (p<0.05). While attention focused on, beta wave energy proportion increased (maximum), and Delta waves’ (0.03~4Hz) the smallest energy ratio (0.410). When sleep occurs, beta waves reduce the proportion of energy (minimum 0.044), while Delta waves (0.03~4Hz) wave energy proportion increased (highest 0.480). When attention turned to the screen alpha waves (8.01~13Hz) reduce the proportion of energy (minimum 0.059).

Analysis of variance showed that attention tendency significantly affected the waveform similarity of EEG spectrum of Delta waves (0.03~4Hz) and original waveform, F=27.333, p<0.01, Delta waves the highest similarity (0.057) of a sleep attack. As shown in table 3. Attention on brain EEG spectra of Alpha 1 waveform similarity has significant effects, F=4.424, p<0.01, similarity of a sleep attack (0.014). Attention influences on Alpha 2 wave’s similarity markedly, F=3.972, p<0.01, most similar to thinking other things (0.015). Attention influences on Beta 1 similarity was more significant, F=3.116, p<0.05, most similar to thinking other things (0.002). Alpha waveform similarity has significant effects, F=12.678, p<0.01, pay attention to screen most similar (0.019). Attention on beta waveform similarity has significant effects, F=9.156, p<0.01, most similar to thinking other things (0.016). See in table 3. Attention on Theta similarity and Beta 2 similarity effects were not significant.

When note the screen(ATS), Alpha (8.01~13Hz) with the most similar to the original waveform (0.019), indicating that associated with the attendance. AO Theta (4.01~8Hz) with the most similar to the original waveform (0.070) and, secondly, Beta 2 (20.01~30Hz) a high similarity (0.004), associated with movement and energy. Sleep onset or doze off(S) Delta waves (0.03~4Hz) with the most similar to the original
waveform (0.057) and, secondly, Alpha 1 (8.01~10Hz) a high similarity (0.004), indicating that associated with sleepy and sleep attacks. TO, alpha 2 (10.01~13Hz) is with the most similar to the original waveform (0.015). And, secondly, Beta 1 (13.01~20Hz) a high similarity (0.004), reflects the attention needs and the relevance of mental processing. Band waveform similarity with the original waveform is a good indicator to studies of brainwave spectrum function.

Table 3. ANOVA of Attention State for EEG Spectral Subband Cosine Similarity.

<table>
<thead>
<tr>
<th>Attention State/ANOVA</th>
<th>Delta</th>
<th>Theta</th>
<th>Alpha_1</th>
<th>Alpha_2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>TO</td>
<td>994</td>
<td>-0.049</td>
<td>0.210</td>
<td>0.059</td>
</tr>
<tr>
<td>S</td>
<td>300</td>
<td>0.057</td>
<td>0.233</td>
<td>0.062</td>
</tr>
<tr>
<td>AO</td>
<td>300</td>
<td>-0.002</td>
<td>0.235</td>
<td>0.070</td>
</tr>
<tr>
<td>ATS</td>
<td>3728</td>
<td>-0.049</td>
<td>0.206</td>
<td>0.068</td>
</tr>
<tr>
<td>F</td>
<td>27.233</td>
<td>1.026</td>
<td>4.424</td>
<td>3.972</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.380</td>
<td>0.004</td>
<td>0.008</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Beta_1</th>
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<th>Alpha</th>
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<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>TO</td>
<td>994</td>
<td>0.002</td>
<td>0.052</td>
<td>-0.001</td>
</tr>
<tr>
<td>S</td>
<td>300</td>
<td>-0.001</td>
<td>0.047</td>
<td>0.000</td>
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<tr>
<td>AO</td>
<td>300</td>
<td>-0.002</td>
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<td>0.004</td>
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<tr>
<td>ATS</td>
<td>3728</td>
<td>-0.003</td>
<td>0.053</td>
<td>0.000</td>
</tr>
<tr>
<td>F</td>
<td>3.116</td>
<td>1.397</td>
<td>12.678</td>
<td>9.156</td>
</tr>
<tr>
<td>P</td>
<td>0.025</td>
<td>0.242</td>
<td>0.000</td>
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</tr>
</tbody>
</table>

* Waveform similarity is the cosine similarity of the band wave and the original waveform.

Discussions

Hit rate of monitoring performance and response time performance together reflects the attention State, that most focused performance is best when note the screen, look elsewhere, thinking or sleeping are distracting, so the monitor performance decline.

Associated attention and pupil diameter, the diameter size of the pupil reaction of visual energy, miosis when visual fatigue, but also exist when the diameter of the pupil while attention distracted but performance decreased, as elsewhere(AO), the pupil diameter is still high but performance reduces. Sleep attack(S) pupil diameter reduce and the monitor performance decline. To think other things (TO), miosis, and performance has declined.

Goal-directed behavior, such as sustained attention28, requires a mechanism for the selective prioritization of contextually appropriate representations. While attention focused on (ATS), beta wave energy proportion increased (maximum), and Delta waves (0.03~4Hz) the smallest wave energy (0.410). When sleep occurs, beta waves reduce the proportion of energy (minimum 0.044), while Delta wave (0.03~4Hz) energy proportion increased (highest 0.480).

When attention turned out of the screen the alpha waves (8.01~13Hz) reduce the proportion of energy (minimum 0.059). Beta wave activity enhancement and Alpha wave
interrupted indicates increase in mental processing activities, attention and attention turned to other parts of the screen are psychological processing activities to strengthen, rather than weaken it.

When note the screen (ATS), Alpha (8.01~13Hz) with the most similar to the original waveform (0.019), indicating that associated with the attendance. Other local (AO) Theta (4.01~8Hz) with the most similar to the original waveform (0.070) and, secondly, Beta 2 (20.01~30Hz) a high similarity (0.004), associated with movement and energy. Sleep onset or doze off(S) Delta waves (0.03~4Hz) with the most similar to the original waveform (0.057) and, secondly, Alpha 1 (8.01~10Hz) a high similarity (0.004), indicating that associated with sleep and sleep attacks. Other issues (TO), alpha 2 (10.01~13Hz) is with the most similar to the original waveform (0.015). And, secondly, Beta 1 (13.01~20Hz) a high similarity (0.004), and the attention needs to and the relevance of mental processing.

Conclusions

Pupillary size reflecting in part the Attention State, but for the dispersion of attention cannot be differentiated along with performance to better distinguish the attention state.

The brain EEG spectrum frequency-band energy ratio can reflect the frequency band activity enhancement and relevance of mental processing, embodies the characteristics of EEG spectral advantage activity with a specific mental processing. Brainwave spectrum frequency-band energy ratio can be used as indicators of recognition of the advantages of brain activity.

Band waveform similarity with the original may reflect a certain psychological advantage frequency EEG activity. Waveform similarity in this study reflects the monitoring task 4 kinds in the Attention State. Waveform similarity can be used as indicators of brain signals recognition of the advantages.

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