

Review of electroencephalography signals approaches for mental stress assessment

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ABSTRACT

يدعم ابتكار تخطيط كهربية الدماغ (EEG) منذ أكثر من قرن تقنية تقييم بنية الدماغ ووظيفته في تطبيقات الصحة السريرية والبحثية. تم تحديد إشارات EEG في نطاقات التردد الخاصة بها مثل دلتا (من 0.5 إلى 4 هرتز)، ثيتا (من 4 إلى 7 هرتز)، ألفا (من 8 إلى 12 هرتز)، بيتا (من 16 إلى 31 هرتز)، وجاما (من 36 إلى 90 هرتز). التوتر هو إحساس بالتوتر العاطفي الناتج عن العديد من أحداث الحياة. على سبيل المثال، القلق بشأن شيء ما، والتعرض للضغط، ومواجهة تحديات كبيرة هي أسباب التوتر. يتأثر جسم الإنسان بالإجهاد بطرق مختلفة ويعزز الالتهاب مما يؤثر على صحة القلب. يتم تنشيط الجهاز العصبي اللاإرادي أثناء الإجهاد العقلي. يعد اضطراب ما بعد الصدمة ومرض الزهايمر من اضطرابات إجهاد الدماغ الشائعة. تم استخدام عدة طرق سابقاً لتحديد التوتر، على سبيل المثال، التصوير بالرنين المغناطيسي والتصوير المقطعي المحوسب بانبعث فوتون واحد و EEG. يحدد مخطط كهربية الدماغ النشاط الكهربائي في دماغ الإنسان من خلال تطبيق أقطاب كهربائية صغيرة موضوعة على فروة رأس الدماغ. إنها طريقة مفيدة غير جراحية وتجمع التعليقات من هرمونات التوتر. بالإضافة إلى ذلك، يمكن أن تكون بمثابة أداة موثوقة لقياس الإجهاد. علاوة على ذلك، فإن تقييم الإجهاد البشري في الوقت الفعلي أمر معقد وصعب. توضح هذه المراجعة قوة نطاقات التردد للضغط النفسي وسلوكيات نطاقات التردد بناءً على الخبرة الطبية والبحثية.

The innovation of electroencephalography (EEG) more than a century ago supports the technique to assess brain structure and function in clinical health and research applications. The EEG signals were identified on their frequency ranges as delta (from 0.5 to 4 Hz), theta (from 4 to 7 Hz), alpha (from 8 to 12 Hz), beta (from 16 to 31 Hz), and gamma (from 36 to 90 Hz). Stress is a sense of emotional tension caused by several life events. For example, worrying about something, being under pressure, and facing significant challenges are causes of stress. The human body is affected by stress in various ways. It promotes inflammation, which affects cardiac health. The autonomic nervous system is activated during mental stress. Posttraumatic stress disorder and Alzheimer's disease are common brain stress disorders. Several methods have been used previously to identify stress, for instance, magnetic resonance imaging, single-photon emission computed tomography and EEG. The EEG identifies the electrical activity in the human brain by applying small electrodes positioned on the scalp of the brain. It is a useful non-invasive

method and collects feedback from stress hormones. In addition, it can serve as a reliable tool for measuring stress. Furthermore, evaluating human stress in real-time is complicated and challenging. This review demonstrates the power of frequency bands for mental stress and the behaviors of frequency bands based on medical and research experience bands based on medical and research experience.

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Mental stress is defined as the response of the brain and body to pressure. The source of pressure may be arguable, such as a routine at work or school, a considerably complex situation, or a painful event. Stress can affect health in advanced situations.¹ Therefore, it is essential to pay attention to dealing with minimal and significant stressors. Several categories of stress carry physical and mental health risks.² Stress signals occur as fight-or-flight reactions in high-risk situations. In these circumstances, the autonomic nervous system is stimulated by stress through the central neural pathways because the cause of prolonged stress is more continuous than acute stress.^{3,4} Frequent stress can disrupt the cardiovascular, digestive, immune, sleep, and reproductive systems.^{5,6} Stress responses

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are associated with the enhanced secretion of many hormones, including adrenaline, noradrenaline, and cortisol.⁷ The cortisol test is a clinical procedure for stressors.⁸ Over time, stress may promote severe health problems such as heart disease, brain disease, high blood pressure, depression, and anxiety.⁹

Biosignals that can assess stressors involve physiological instrumentation such as electroencephalography (EEG), electrocardiography (ECG), and electromyography (EMG), which can measure bodily parameters (skin temperature, eye activity, respiratory rate, pupil size, and speech).¹⁰ The following text outlines some of the band's power used in stress research areas. However, numerous bands of power exist for stress analysis in the laboratory.

Each brain has 4 lobes; the frontal lobe is vital for thinking and controlling voluntary movements or actions, the parietal lobe handles communication about temperature, taste, touch, and training, the occipital lobe is mostly accountable for the visual sense, and the temporal lobe manages memory and integrates it with taste, sound, sight, and touch. The best way to quantify the neuronal activity of the human brain is using an EEG, which is one of the oldest instruments developed over a century ago.¹¹ Its use is unquestionable in clinical diagnoses for conditions such as epilepsy and sleep disorders and for evaluating dysfunction in sensory transmission pathways.¹² The EEG has developed over the years since its invention by Richard Caton in 1875.¹³

He found the first EEG from the brains of animals such as monkeys and rabbits.¹⁴ In 1924, scientist Hans Berger created and invented the first EEG recording on the human scalp by utilizing a radio kit to magnify the brain's electrical signals. He claimed that stable, reproducible and clear EEG changes could be seen during alterations in body conditions such as from relaxation to alertness, sleep, or hypoxic conditions.¹⁵ In 1934, the EEG idea was developed by Adrian and Matthews, validating the theory of "human brain ranges" and found normal fluctuations approximately from 10 to 12 Hz, and they named it "alpha waves".¹⁶ These achievements and innovations became the springboard for research on the diverse functions of EEG use. In addition, EEG frequently provides an entirely non-invasive procedure without any limitations to patients, healthy adults, and children.¹⁷ For brain wave classification, an EEG recording is required for individuals depending on the application or research area. The subjects are asked to close their eyes and relax to obtain stable electrical signals from the detector.¹⁷

They are frequently quantified from the highest peak signals and scale from 0.5 to 100 μ V in amplitude,

which is approximately 100 times smaller than ECG signals.¹⁸ The EEG waveforms are described based on their amplitude, location, frequency, symmetry, and reactivity.¹⁹ Frequency is the most commonly utilized technique for classifying EEG waveforms. The standard bandwidth of the clinical EEG signal analysis extends from 0.5 Hz to 70 Hz. This evaluation was performed by bandpass filtering of the EEG recorded signals. The EEG waves are labeled with Greek numerals as delta (from 0.5 to 4 Hz), theta (from 4 to 7 Hz), alpha (from 8 to 12 Hz), beta (from 13 to 30 Hz), and gamma (from 30 to 80 Hz).²⁰ The raw EEG signal is the signal extracted from EEG recordings and may include some non-cerebral signs known as artifacts. These are faults in the signal, such as movement potentials, eye movements, and changes in facial muscles. Occasionally, signals similar to ECG and EMG are combined with EEG signal recordings.²¹ Recording faults are referred to as biomedical artifacts. Artifacts are highly challenging to distinguish, as these resemble real raw EEG signals. Another type of artifact is environmental, such as power line noise from AC, pulse, electrode stabilization, and preparation for subject recording.

Removing physical artifacts is vital from a health viewpoint as a slight error in understanding the EEG signal may have critical repercussions.²² After the signal is prepared and filtered, several methods should be used to obtain the real signal. Feature extraction is one of the methods to analyze these signals. The feature extraction method is typically performed by applying statistical techniques.²³ Subsequently, the signal is classified using machine learning techniques such as support vector machines or neural networks.^{24,25} Bandpass filtering is applied to remove artifacts from the EEG recordings. Removal of the lower- or higher-band signals of the EEG frequency spectrum is a normal practice. Unfortunately, EEG calculations may lose various significant physiological and pathological features extracted from brain activity.^{26,27}

The 10–20 system is the traditional electrode placement method employed for collecting raw EEG data and is the standard method for existing databases.²⁸ According to the EEG electrode, each electrode position is characterized by a letter corresponding to the lobe area. Even numbers signify the right area and odd numbers point to the brain's left area.²⁹ The following text shows the EEG waveforms in clinical disorders.

EEG WAVEFORMS. Delta (from 0.5 to 4Hz).

Delta waves are observed in high levels of deep-sleep conditions and are found in the frontocentral brain

areas.³⁰ Uncontrolled delta waves are present in awake states in generalized brain disorders.³¹ Usually, frontal intermittent regular delta activity is described in individuals. Conversely, the occipital periodic rhythmic delta activity is observed in children.³² Moreover, temporal normal rhythmic delta waves are commonly found in individuals with temporal lobe epilepsy.³³ These waves are associated with tiredness and early stages of sleep. Delta waves are highly obvious within the frontal and central head areas. However, it slowly moves backward in the brain, substituting the alpha wave because of early tiredness.³⁴

Theta (from 4 to 7Hz). The relationship between creativity and daydreaming is a repository of memories, emotions, and sensations.³⁵ Theta waves are strongly observed in situations requiring focus and hypervigilance or during meditation, prayer, and awareness.³⁶ Theta waves show the relationship between wakefulness and sleep. Enhanced emotional states might improve frontal regular theta waves in children and young adults.³⁷ Furthermore, focal theta action in conscious circumstances indicates focal cerebral dysfunction.³⁴

Patients suffering from attention-deficit hyperactivity disorder (ADD, ADHD), stroke, epilepsy, and head injuries can have extremely slow delta waves, normal theta waves, and rarely produce additional alpha waves.³⁸

Alpha (from 8 to 12Hz). In EEG recordings, alpha waves in the occipital head area appear in the normal awake state. In healthy individuals, alpha waves are found as short variants.³⁹ Previous research has suggested that slowing of environmental alpha waves is a sign of cerebral dysfunction.⁴⁰ The best visualization of alpha rhythm is seen when individuals have their eyes closed and rest and is reduced due to eye-opening and conceptual thought.⁴¹ Patients under stress disorder could not represent simplified alpha activity. It is non-reactive to internal or external motivations and expands to be called “alpha coma”.⁴² Moreover, “Mu rhythm” is another variety of alpha waves that appear within the central head areas.⁴³

Beta (from 13 to 30Hz). Beta waves are the most frequently observed waves in adults and children. This is obvious around the frontal and central head zones.⁴⁴ The amplitude of the beta wave is typically 10–20 μ V and regularly rises during drowsiness.⁴⁵ In the sleep stages, beta waves are present in stage N1 sleep and subsequently reduced in stages N2 and N3 sleep.⁴⁶ Beta waves are important because most sedative medications, chloral hydrate, and benzodiazepines enhance the scale and quantity of beta action in individuals.⁴⁷

Focal and regional beta waves can appear together through cortical, subdural, and epidural injuries.⁴⁸ Beta relates to the conditions of thinking, mental and intellectual activity, and concentration.

This is the dominant wave when the eyes are open. Beta occurs during hearing and imagination as a result of analytical problem solving, judgment, and decision making.

Gamma (from 30 to 80Hz). Gamma waves have been recognized in sensory perception integrating various areas. In previous studies on epilepsy, epileptic foci produce periods of high-frequency activity. Intracranial strength recording signals from the epileptic hippocampus have revealed ultrafast frequency bursts, which are probably connected to the local epileptogenicity of brain tissue.^{19,49}

A faster EEG activity is associated with mental conditions and result-associated abilities. The significance of gamma patterns in a variety of cognitive purposes has been studied.⁵⁰ Brain stem-induced possibilities are a highly selected and consistently quantified classification of faster EEG signals.¹⁹ Gamma-feeling states involve thinking, integrating thoughts, and learning. In addition, they correlate tasks and behaviors with high-level knowledge management. Table 1 shows the relationship between mental stress and the EEG band power.

Discussion. The mental stress test is performed with a stressor(s) conducted in a laboratory setting. Several EEG power band tests were performed a decade ago for stress assessments. Five EEG power bands were identified based on EEG data acquisition and clinical experience.

Delta brainwaves are prolonged, have a high amplitude, and do not provide certain diagnostic signs. Delta brainwaves appear when the brain areas develop offline to begin nutrition, and delta is additionally linked with educational disabilities.⁵¹ Delta waves are produced by the brainstem and cerebellum. This indicates an unconscious mind. Delta waves usually reduce our awareness of physical activity.⁵² The delta wave appears to be able to access data in our unconscious minds.⁵³ Delta waves are practical for brain healing from stress.⁵⁴ Theta brainwave activity generally indicates mental ineffectiveness. Theta brainwave action appears in an extremely comfortable situation, which is a twilight zone between waking and sleep. It is also used in neurofeedback treatment.⁵⁵

When theta is high, the brain is employed overtime to recruit resources. Theta is caused by the thalamocortical

path and indicates the resources employed in the body.⁵⁶ High theta levels in the posterior region of the brain tend to be quiet and highly associated with the subconscious state. Theta is involved in anxiety, behavioral activation, and inhibition.⁵⁷

The benefits of theta bands, when available, mediate and promote complicated education and memory.⁵⁸ In rare emotional conditions, for example, stress, there may be an imbalance of the three foremost transmitter systems. In addition, a high theta/beta ratio is indicative of ADHD.⁵⁹

The alpha brainwaves are slower and more widespread. Alpha is caused by a resonance between the thalamus and the cortex.⁶⁰

Alpha is commonly used because it is related to relaxation and peacefulness. These brain bands were particularly prominent in the third part of the head area

EEG studies of alcoholics have identified alpha waves only after extended cycles of abstinence. In addition, they regularly have smaller degrees of alpha and theta brain bands and additional rapid beta action.⁶¹ Outstanding alpha formation encourages mental creativity, aids in mental coordination, and improves the general sense of meditation and fatigue.⁶² Alpha waves develop from the white matter of the brain.⁶³ Alpha waves are highly substantial from the frontal and occipital cortex.⁶⁴ Alpha waves are more prominent in the right cerebral hemisphere than within the left hemisphere.⁶⁵ Alpha asymmetry and closeness by the grown alpha waves are indicative of depression. Low alpha waves can indicate metabolic difficulties, toxins, depression, and body abuse.⁵¹ An enhanced fast alpha in the posterior region may indicate emotional rumination. Alpha is associated with extroversion, creativity, and

Table 1 - Mental stress and EEG band power relationship.

EEG Waveforms	Relation to mental stress	EEG waveforms behavior
Delta (0.5 to 4 Hz)	Delta waves are associated with healing and regeneration during our deep sleep cycles. A few minutes of allowing our brains to tune into delta waves can decrease overactivity and stress of anxious thinking ^{30,31}	Excessive: Brain injuries, learning problems, inability to think, severe ADHD Inadequate: Inability to rejuvenate the body, inability to revitalize the brain, poor sleep Optimum: Immune system, physical treatment, restorative / intense sleep ³⁴
Theta (4 to 7 Hz)	Theta is detected in anxiety and behavioral with activation and inhibition. When the theta wave occurs, it mediates and promotes interesting behaviors, for example, learning and memory. Under uncommon emotional situations, for instance, stress, there may be an imbalance of three key transmitter systems, which results in aberrant behavior ³⁵⁻³⁷	Excessive: ADHD, unhappiness, hyperactivity, impulsivity, daydreaming Inadequate: Nervousness, low emotional perception, stress Optimum: Imagination, emotional relationship, intuition, rest ³⁸
Alpha (8 to 12 Hz)	Regular meditation and relaxation have been shown to enhance alpha waves and lower beta waves in the brain waves of effective thought and learning. This is the reason why it is the most recommended for lowering stress. When alpha's reaction is non-existent or negative, the possibility of traumatic stress is suspected. In most harshly emotionally distressed fibromyalgia patients, the QEEG showed relatively minimal alpha activity and the most considerable alpha power in the group with the least emotional distress ³⁹⁻⁴¹	Excessive: Dreaming, inability to concentrate, too calm Inadequate: Nervousness, high stress, insomnia, OCD Optimum: Rest ⁴²
Beta (13 to 30 Hz)	Stress, "traffic jam," overwhelmed, cannot process activated networks. Beta wave is increased during stress ^{44,45}	Excessive: Adrenaline, high arousal, failure to relax, stress Inadequate: ADHD, daydreaming, depression, poor cognition Optimum: Conscious focus, memory, problem-solving ⁴⁸
Gamma (30 to 80 Hz)	A fully standardized task with high ecological validity ⁴⁹	Excessive: Nervousness, high-level arousal, stress Inadequate: ADHD, depression, knowledge disabilities Optimum: Binding senses, cognition, knowledge handling, learning, awareness, REM sleep ⁵⁰

mental work. Low alpha power might be symptomatic of anxiety, PTSD, or short-term memory impairment.⁶⁶ Low alpha increases cortisol in the brain, which affects the hippocampus and short-term memory, and research demonstrates stress results on the neuronal composition of the hippocampus, amygdala, and prefrontal cortex.⁶⁷ The alpha band is judged to be the most valuable frequency band of the brain for learning and using the information demonstrated.⁶⁸

Beta is a small and relatively fast brainwave. This is a condition of alertness.⁶⁹ If beta is insufficient, either all over or in small regions, the brain may have inadequate energy to meet peer group standards.⁷⁰ Beta represents desynchronized active brain tissue. The beta must be superior on the left than on the right.⁷¹ Heightened beta asymmetry in the right hemisphere is indicative of anxiety or stress.⁷²⁻⁷⁸ Extreme beta waves may lead to stress circumstances.⁷³ Gamma waves are rapid, and some gamma activity is associated with intensely focused attention.⁵⁰ A decent memory is connected with a regulated and efficient 40 Hz action, although a 40 Hz deficiency generates educational disabilities.⁵¹ When trained, it develops memory, language, and effortlessness during learning. Extreme gamma waves may lead to stress situations.⁵⁴ This review addresses several outstanding questions.⁵⁵ In conclusion a comprehensive set of comparisons was performed in this review between the EEG power bands methods, and mental stress was widely used in lab sitting or clinical health. These comparisons' goal was to show the relevance and effective way to select the more convenient specific research areas related to mental stress and consider some bands' power features, limitations, and disorders. These bands are effectively produced by EEG for stress detection to treatment. Bands power evaluation is generally employed to explore the mechanisms relating to psychological stress. EEG can understand the nervous system disease consequences and predict death risk, insensitive peoples. However, some mental stress examinations have not been fully identified, which weakens their trustworthiness and legitimacy as a research and clinical tool.

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