# A Stress Level Monitoring System for Rescue Teams During Search and Rescue Operations Based on Electroencephalography

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***Abstract*—Search and Rescue (SAR) officers work in high-risk conditions that require physical and mental resilience. Prolonged stress can affect the performance and success of SAR operations. This study evaluates the effectiveness of Electroencephalography (EEG) coherence analysis as a method for monitoring stress in SAR personnel. Using the OpenBCI EEG device and electrodes in the F3 and F4 areas, the brain activity of SAR personnel was recorded in two conditions, office activity (baseline) and rescue operations (SAR condition). The data collection for this research involved the same participants in both baseline and SAR operation conditions, resulting in 30 raw EEG data for further analysis. Data collection on operational conditions was carried out while the rescue officers conducted a search and rescue operation for a capsized boat in the Bengawan Solo River, Ngadirejo Village, Tuban Regency. Data analyzed based on coherence values obtained through the Power Spectral Density (PSD) features of alpha, beta, and gamma sub-band to detect changes related to stress levels. The results showed an increase in coherence in the alpha sub-band by 85.5%, beta sub-band by 92.9%, and gamma sub-band by up to 94.9% during moderate stress conditions, reflecting increased attention, alertness, and intensive information processing required in emergency situations. These findings indicate that EEG coherence analysis can be an effective tool for monitoring stress in SAR personnel in real-time.**

***Keywords*— coherence analysis, eeg, stress, visual simulation.**

## I. INTRODUCTION

Search and Rescue (SAR) personnel are individuals who often work in extreme situations and face psychological pressure, especially in emergencies or natural disasters. In high-risk situations, personnel must make quick decisions and bear significant responsibilities, which can increase physical and mental pressure on them. It can negatively impact the performance and mental health of personnel if left unresolved for too long [1].

In such situations, the increased level of pressure is not only a problem for an individual's personal safety but can also negatively impact the success of rescue efforts, which require quick and precise decisions [2]. Therefore, directly monitoring the stress levels of SAR personnel is very important to reduce risks and maintain operational performance in emergency situations [3].

The application of EEG technology to stress monitoring has improved significantly in the last few decades. EEG is a technique for capturing brain electrical activity that can identify trends associated with emotional and mental health issues, such as stress [4-10]. By using frequency analysis such as alpha, beta, and gamma sub-bands, EEG can identify changes in brain activity associated with various levels of stress [11]. These frequencies are crucial for stress monitoring, as alpha sub-band indicates a relaxed state, beta sub-band indicates a vigilant state, and gamma sub-band indicates intense thinking activity. EEG analysis can show personnel stress responses by observing these frequency changes [12]. EEG coherence, which measures the degree of signal synchronization between various brain areas, is one analytical technique used to observe how stress impacts communication across brain regions [13]. According to other studies, stress may significantly alter EEG activity, especially in the frontal region, which is implicated in attention, emotion control, and decision-making [14].

Because the EEG channels F3 and F4 are intimately linked to cognitive and emotional processes that are frequently impacted under stress, they were selected for this investigation. Decision-making and emotion control are linked to the channels in the left frontal region (F3) and right frontal area (F4) [15]. EEG analysis has been used in a number ofresearch to create stress monitoring models. The findings indicate that the coherence patterns between EEG channels might be impacted by stress [16].

Numerous studies have effectively used EEG to detect stress patterns by observing alterations in brain activity under both low- and high-stress circumstances [17]. Research on EEG stress monitoring in high-risk work settings, like SAR teams, is still lacking, nevertheless. Indeed, precise stress monitoring under these circumstances may enhance staff members' mental toughness and decision-making skills in emergency scenarios [18].

This study attempts to assess the efficacy of EEG coherence analysis in tracking stress levels among National SAR Agency SAR officers based on prior studies. This study looks for coherence variations that signify high stress during emergency condition simulations utilizing the alpha, beta, and gamma frequencies from the EEG channels F3 and F4. In order for SAR personnel to perform better during field search and rescue operations, it is intended that the findings of this study will be utilised as a foundation for the creation of a real-time stress monitoring system [19].

## II. METHODS

Fig. 1 shows that this work is divided into four main stages that are carried out sequentially.

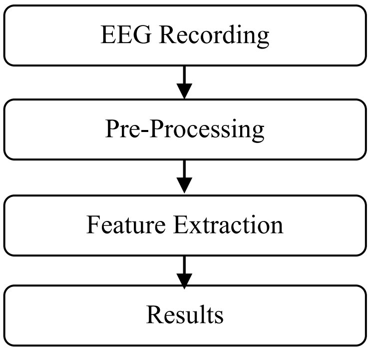


Fig.1. Stages of the Research

### A. *EEG Recording*

The aim of this research is to evaluate the stress levels of SAR personnel using the EEG method in two situations, office activities (Baseline) and rescue operations (SAR condition). Each participant was provided with an informed consent letter to indicate their agreement to participate in the study, in accordance with the medical research ethics protocol [20]. Next, participants were asked to fill out the Depression Anxiety Stress Scales (DASS-42), a tool that measures levels of stress, anxiety, and depression (self-validation method)[21]. This scale is used to identify the initial psychological conditions of the participants. This study involves 6 SAR personnel who have worked for at least five years at the National Search and Rescue Agency. To ensure that the data collected is relevant and reliable, participants were selected based on their physical and mental health without a history of neurological disorders.

To record EEG signals, this research uses the OpenBCI device. (Open Source Brain-Computer Interface). Compared to medical EEG devices typically used in large-scale research, OpenBCI was chosen for its advantages, such as portability, ease of use, and lower cost. This OpenBCI device consists of an eight-channel Cyton board for data processing and two main components of the Ultracortex "Mark IV" headset mounted on the head. Calibration of the OpenBCI device was conducted prior to data collection to guarantee the quality and authenticity of the data. This procedure involves verifying electrodes, impedance, device configurations, and signal testing to confirm that all systems are operating correctly prior to data collection.

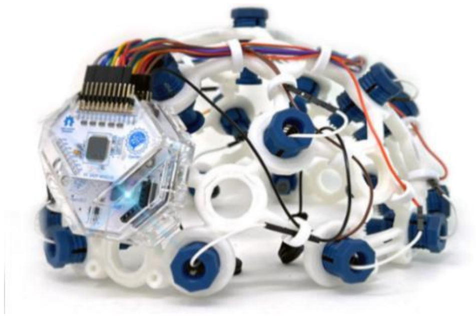

Fig. 2.EEG OpenBCI Ultra Cortex

The electrodes employed to measure stress in this investigation are F3 and F4. The F3 and F4 electrodes are situated in the frontal lobe, which is integral to emotion processing, decision-making, and attention. Engagement in this domain is crucial for rescue professionals, particularly in scenarios that need heightened focus and emotional regulation [22-23]. F3 is linked to emotional processing and reaction regulation, whereas F4 pertains to situational assessment and decision-making in high-stress environments [24].

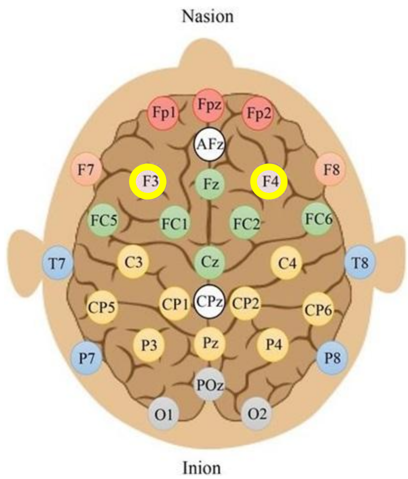


Fig.3. Electrode Placement [25]

EEG data collection was conducted in two conditions, the office activity condition (Baseline) and rescue operation condition (SAR Condition). In the office condition (baseline), participants provided informed consent to express their agreement to participate in the study and fill out the Depression Anxiety Stress Scales (DASS-42). EEG data recording in a relaxed state with eyes closed for 5 minutes was carried out in a quiet office room where participants were asked to remain still and not speak to minimize disturbances or artifacts on the EEG signal [25].

Data collection for the Search and Rescue (SAR Condition) operation is conducted during daily SAR operation evaluation sessions in a safe and controlled location, to ensure that data is collected safely and accurately without disrupting the participants' primary tasks in carrying out search and rescue operations. Before data recording, participants provided written informed consent as an agreement to participate in the medical research and complete the Depression Anxiety Stress Scales (DASS-42).

During the EEG data collection, participants sat in a relaxed position with their eyes closed for 5 minutes, while following a stimulus in the form of a structured evaluation conversation about the challenges and outcomes of search and rescue operations. This conversation stimulus is expected to evoke the conditions experienced during the operation [26]. Data collection under SAR conditions was conducted on the 3rd, 4th, 5th, and 6th days while participants were involved in the search and rescue operation of the capsized ship in the Bengawan Solo River, Ngadirejo Village, Tuban Regency, with 19 victims. At the end of the 7-day SAR operation, 10 people were found alive, 5 people died, and 4 people were declared missing. The participants in this study are the same participants for the baseline condition and the SAR operation condition, resulting in 30 raw EEG recordings for further analysis.

Fig. 4. Baseline condition.

Fig.5. SAR condition.

*B. Pre-processing*

EEG signals and disturbances called artifacts are components of EEG data [28]. The amplitude of the EEG signal usually ranges from ±100 µV [29]. On the other hand, sound can have an amplitude up to 10 to 100 times greater [30]. As a result, EEG signal preprocessing is very important to reduce interference. To improve the quality of EEG data, the preprocessing stage is carried out in three steps, as shown in Figure 6.

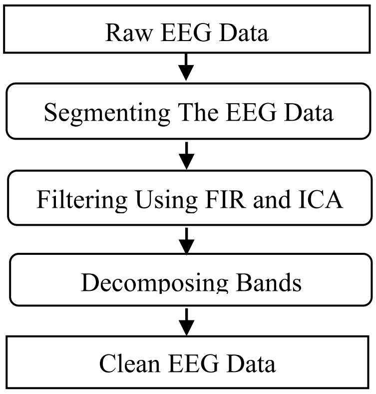


Fig.6. Stages of the preprocessing

Using a Finite Impulse Response (FIR) bandpass filter in the frequency range of 1 Hz to 50 Hz, the EEG data is filtered. This method is illustrated in Figure 8. The purpose of this process is to eliminate frequencies that are outside the necessary limits. Additionally, Independent Component Analysis (ICA) is used to remove artifacts such as muscle activity, heart signals, and eye blinks to obtain more accurate EEG data. Python 3 is used to run bandpass filtering and ICA processing with Scipy. The algorithm used by FastICA in the Python is as follows.

1. FastICA Model

$$X = A \,.\, S \tag{1}$$

$X$ : the mixed data.
$A$ : the separation matrix.
$S$ : matrix of independent source components.

The goal of ICA is to find the matrix $W$ that can separate the mixed data into independent signals $S$.

$$S = W \,.\, X \tag{2}$$

2. Whitening.

Whitening is the step where we transform data $X$ into uncorrelated data, which has uniform variance across all dimensions. Mathematically, whitening is performed using eigenvalue decomposition.

$$X_{whitened} = U \,.\, S^{-1/2} .\, V^T \tag{3}$$

$V^T$ : right eigenvector matrix.
$U$ : left eigenvector matrix.
$S$ : diagonal matrix containing singular values.

Whitening transforms the data so that the data components become uncorrelated and have equal variance.

3. Optimization $W$

The goal of optimizing W in ICA is to separate independent components using statistical techniques that prioritize non-Gaussianity and independence.

$$W_{new} = \frac{1}{N}\sum_{i=1}^{N}(x_i . g^{'}(w^t x_i) - \alpha w) \quad (4)$$

$W$ : the separating vector that is being updated.
$g(x)$ : the activation function used to enhance the non-Gaussianity of the data.
$g^{'}(x)$ : the first derivative of the activation function $g(x)$.
$x_i$ : the data at the i-th iteration.
$\alpha$ : the regularization parameter used to avoid overfitting.

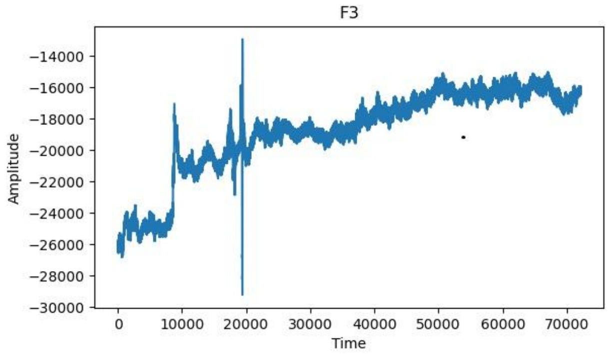


Fig.7. Raw Data.

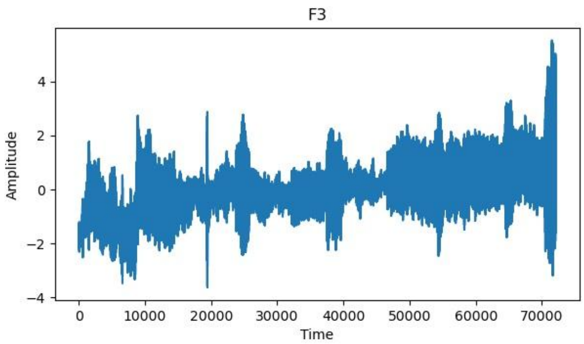


Fig.8. Filtered EEG signal using FIR and ICA

Breaking down the EEG signal into frequency bands is the final step in preprocessing. To achieve this, a 6th-order Butterworth filter is used, which has a cutoff frequency corresponding to the alpha, beta and gamma sub-band range. Separating EEG signals into their frequency components aids in further analysis and interpretation.

## C. Coherence Feature Extraction

The analysis of this feature assesses the relationship between channel pairs under stress. The coherence feature used in the research is the focus of this analysis. Two channel F3-F4 were evaluated. By using a Hann window, a window size of 1 second, and a 25% overlap, the coherence value can be obtained. Using the Welch method, the Power Spectral Density (PSD) formula of the signal is given by Equation (5). Figure 9 shows the plot of the FP3-FP4 pair signal. Next, the formula for the coherence feature using the PSD with the Welch method is found in the equation. (6). A coherence value of 0–1 indicates a stronger correlation between two channels. Figure 10 shows the coherence of the example signal plot.

$$P_{xx}(f) = \frac{1}{M.fs}|X(f)|^2 \quad (5)$$

$P_{xx}(f)$ : The periodogram at frequency$f$
$M$ : The number of samples in the windowed signal segment.
$fs$ : The sampling frequency (samples per second).
$X(f)$ : The Fourier transform of the windowed signal segment at frequency.

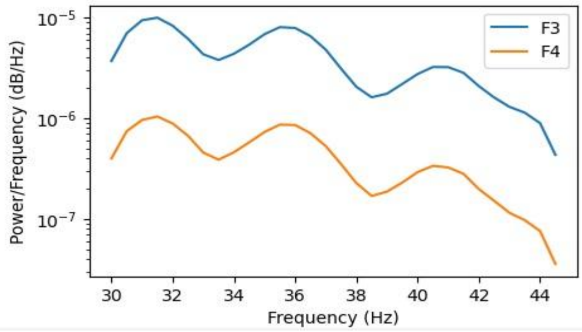


Fig.9. Power Spectral Density (PSD) of signal

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)} \quad (6)$$

$P_{xx}(f)$ : Power Spectral Density of signals x.
$P_{yy}(f)$ : Power Spectral Density of signals y.
$P_{xy}(f)$ : Cross Spectral Density Estimate of x and y.

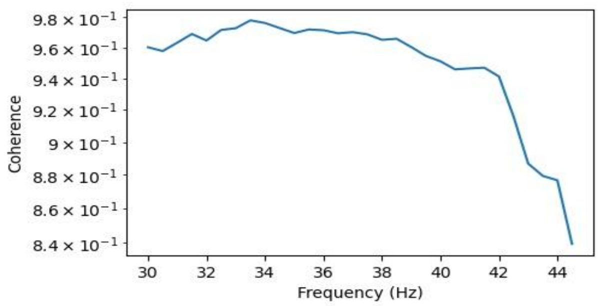


Fig.10. Coherence Between F3 and F4 channels

# III. Results and Discussion

This study analizes EEG coherence data related to stress levels recorded in SAR personil. Three stress level categories Normal, Mild, and Moderate have the F3-F4 coherence data on alpha, beta, and gamma brain sub-bands arranged in them. This information will be examined to find notable variations across stress categories as well as its applicability in the framework of EEG stress study on SAR personnel.

Table.1. The coherence results of Alpha, Beta and Gamma Band .

| Condition | Participant | Channel | Coherence Alpha | Coherence Beta | Coherence Gamma | Stress Level |
|---|---|---|---|---|---|---|
| Baseline | P1 | F3 F4 | 0.035 | 0.130 | 0.155 | Normal |
| | P2 | F3 F4 | 0.410 | 0.465 | 0.434 | Normal |
| | P3 | F3 F4 | 0.306 | 0.203 | 0.112 | Normal |
| | P4 | F3 F4 | 0.226 | 0.129 | 0.189 | Normal |
| | P5 | F3 F4 | 0.227 | 0.060 | 0.100 | Normal |
| | P6 | F3 F4 | 0.410 | 0.465 | 0.434 | Normal |
| SAR 3rd | P1 | F3 F4 | 0.060 | 0.013 | 0.069 | Normal |
| | P2 | F3 F4 | 0.208 | 0.045 | 0.009 | Normal |
| | P3 | F3 F4 | 0.084 | 0.138 | 0.406 | Normal |
| | P4 | F3 F4 | 0.077 | 0.030 | 0.051 | Normal |
| | P5 | F3 F4 | 0.119 | 0.130 | 0.013 | Normal |
| | P6 | F3 F4 | 0.099 | 0.036 | 0.033 | Normal |
| SAR 4th | P1 | F3 F4 | 0.123 | 0.054 | 0.071 | Normal |
| | P2 | F3 F4 | 0.026 | 0.006 | 0.016 | Normal |
| | P3 | F3 F4 | 0.685 | 0.929 | 0.949 | Moderate |
| | P4 | F3 F4 | 0.127 | 0.182 | 0.282 | Normal |
| | P5 | F3 F4 | 0.435 | 0.457 | 0.271 | Normal |
| | P6 | F3 F4 | 0.443 | 0.662 | 0.743 | Moderate |
| SAR 5th | P1 | F3 F4 | 0.218 | 0.068 | 0.154 | Normal |
| | P2 | F3 F4 | 0.637 | 0.727 | 0.760 | Moderate |
| | P3 | F3 F4 | 0.115 | 0.044 | 0.024 | Normal |
| | P4 | F3 F4 | 0.070 | 0.085 | 0.116 | Normal |
| | P5 | F3 F4 | 0.385 | 0.618 | 0.679 | Moderate |
| | P6 | F3 F4 | 0.412 | 0.247 | 0.049 | Normal |
| SAR 6th | P1 | F3 F4 | 0.607 | 0.808 | 0.815 | Moderate |
| | P2 | F3 F4 | 0.659 | 0.733 | 0.724 | Mild |
| | P3 | F3 F4 | 0.409 | 0.527 | 0.249 | Normal |
| | P4 | F3 F4 | 0.855 | 0.814 | 0.823 | Moderate |
| | P5 | F3 F4 | 0.137 | 0.133 | 0.095 | Normal |
| | P6 | F3 F4 | 0.130 | 0.038 | 0.095 | Normal |

### A. *Alpha Sub-Band.*

Under normal conditions, the coherence of Alpha sub-band at the F3-F4 electrode pair is relatively low, indicating a relaxed state with minimal cognitive load. This low coherence reflects inter-regional stability without significant demands on cross-hemispheric processing, which is typical in non-stress situations. In mild conditions, when stress increases to a mild level, Alpha coherence gradually increases, indicating the onset of cognitive engagement, preparing the brain to be more alert. The increase in alpha coherence characterizes a state that is alert but not excessive, supporting cognitive readiness without excessive stress. In moderate conditions, alpha coherence reaches higher levels, and this increased alpha coherence indicates better cortical synchronization, serving as a compensatory mechanism to manage higher cognitive demands. High alpha coherence in stressful conditions indicates an adaptive response where the brain maintains attention and suppresses irrelevant information [31].

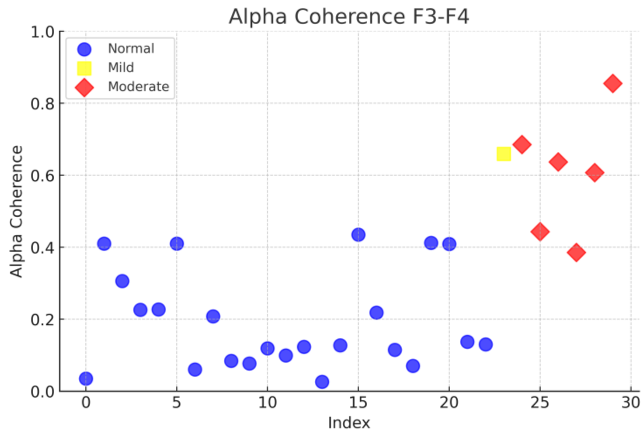


Fig.11. Alpha Coherence F3-F4.

### B. *Beta Sub-Band.*

Beta sub-band coherence is typically low to moderate under normal circumstances, which indicates a cognitive state that is relaxed and has minimal processing requirements. As stress levels increase to a moderate level, beta coherence begins to increase considerably under mild conditions, suggesting a higher level of cognitive engagement that is consistent with mild stress conditions. Focused attention is associated with elevated beta coherence. Beta coherence experiences a considerable increase in moderate conditions. Under moderate stress, sustained attention, problem-solving, and complex cognitive processing are all associated with high beta coherence, all of which are crucial for situational awareness and decision-making [31].

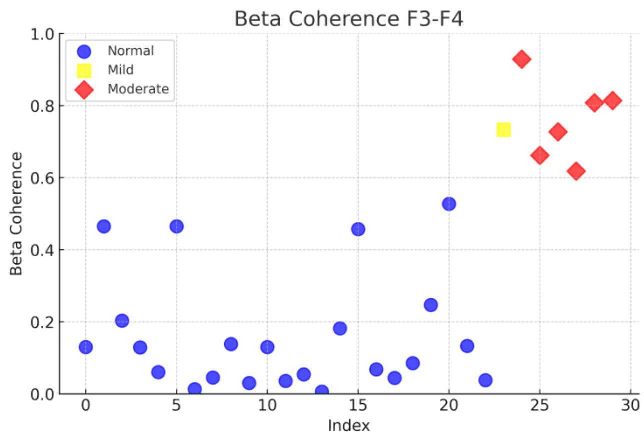


Fig.12. Beta Coherence F3-F4.

### C. *Gamma Sub-Band.*

Gamma sub-band coherence is fairly low with moderate values under normal conditions. Basic cognitive processing is indicated by low gamma coherence, which does not necessitate rapid information integration. Gamma coherence experiences a moderate increase in mild conditions as tension transitions to mild conditions. This increase suggests that the individual is prepared for more intricate duties and is cognitively engaged. Gamma coherence reaches its maximum under moderate conditions. The brain's requirement for rapid decision-making and intensive information processing is illustrated by the presence of high gamma coherence in moderate stress scenarios [31].

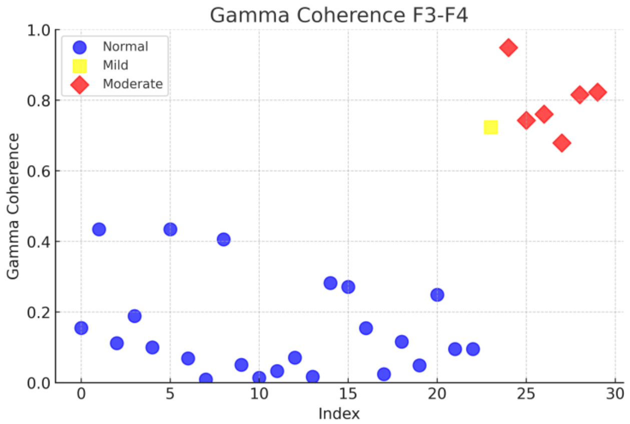


Fig.13. Gamma Coherence F3-F4.

*D. Discussion.*

These results show significant EEG coherence in the higher stress categories, particularly in the beta and gamma sub-bands. High stress and attention conditions are often associated with increased beta and gamma activity. While gamma sub-band are linked to complex data processing and heightened emotional states, beta sub-band typically increase when a person feels stressed or concentrated. Increased alpha activity and coherence of alpha sub-band in SAR personnel can indicate mild to moderate stress levels, reflecting the body's efforts to maintain balance or manage stress. Studies show that increased alpha activity can indicate efforts to remain calm in high-pressure situations. This is an important feature of SAR operations. SAR personnel with moderate stress levels may experience increased alertness and feelings of anxiety, as indicated by the increased coherence of beta sub-band. This is important for SAR operations, where a high level of attention and awareness is required for the success and safety of the operation. Highly intensive cognitive processing activity is indicated by increased gamma sub-band coherence at moderate stress levels. This can be considered a response to urgent or critical needs in specific situations. SAR personnel who are in dangerous situations or have casualties often experience increased gamma levels of stress, indicating a strong physiological and emotional response to emotional stress.

## IV. CONCLUSION

The coherence of alpha ranges from 2.6% to 43.5%, beta from 0.6% to 52.7%, and gamma from 0.87% to 43.4% under normal conditions. These values indicate a calm state where the brain is not overly burdened. SAR personnel are in a stable psychological and emotional condition with little external pressure. The coherence value is higher compared to normal conditions during mild stress. Alpha coherence 65.9%, beta 73.3%, and gamma 72.4%. However, not at a significant stress level, this increase indicates higher cognitive engagement and improved alertness. In moderate stress conditions, the coherence values of all three sub-bands exhibited a substantial increase, with the alpha sub-band exhibiting the highest coherence at 85.5%, the beta sub-band at 92.9%, and the gamma sub-band at 94.9%. This increase indicates more intensive brain activity. This activity involves deeper information processing and greater vigilance when facing situations that require quick decision-making. Specifically, the increase in gamma sub-band indicates complex cognitive activity that is usually associated with high-stress situations.

The increase in coherence in alpha, beta, and gamma sub-bands indicates that EEG can be an effective tool for monitoring stress in SAR personnel. The increase in beta sub-band activity by 92.9% and gamma by 94.9%, especially at higher stress levels, indicates the brain's reaction to critical situations by enhancing attention and information processing. The increase in beta and gamma sub-bands is associated with stress and intense cognitive activity, according to previous research [31]. As a result, this research can make a significant contribution to the fields of neuropsychology and medicine, particularly in the development of interventions that can reduce the stress of SAR personnel in real-time using EEG technology.

Recommendation for future research, to utilize machine learning to predict stress levels based on EEG coherence patterns and other variables, can help create a more accurate early detection system.

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