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# Identifying the Impact of Noise-Levels on Mental Stress: An EEG-fNIRS Study

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**Abstract.** Stress is a complex response that begins when people are exposed to various stressors, including psychological and environmental factors, which are associated with negative cognitive effects. However, little is known about their interactions within the brain. This research aimed to examine the influence of low and high noise levels in the workplace on changes in brain activity in the prefrontal cortex (PFC) during stressful psychological tasks by measuring synchronized functional near-infrared spectroscopy (fNIRS) and electroencephalogram (EEG). The results showed a decreased oxygenated haemoglobin (HbO) concentrations in the right dorsolateral PFC and part of the frontopolar area when exposed to higher noise levels compared to lower levels. Results also showed a higher correlation between fNIRS-HbO and EEG-alpha power under stress conditions compared to other EEG bands. We suggest that higher levels of noise in the workplace may be directly related to increased psychological stress.

**Keywords:** Occupational stress, prefrontal cortex (PFC), environmental noise, electroencephalography, functional near-infrared spectroscopy (fNIRS).

## 1. Introduction

These Noise-related stressors in the workplace are a common exposure in the work environment that affects cognitive performance by interfering with the decision-making process [1, 2]. Previous research has found that exposure to noise affects health, working memory, alertness, and job satisfaction [3-5], which varies depending on the complexity of the task. For example, Wright et al. reported that noise did not affect simple tasks, but played a role in more complex tasks [5]. Noise is also likely to affect a worker's performance, not only through chronic exposure but also through acute

exposure at high levels [6, 7]. According to Leather, Beale and Sullivan [4], decreasing ambient noise at work appears to reduce the negative effects of psychosocial stress at work.

Stressors can also be cognitive. In actual situations, stress is a mixture of cognitive (for example, time pressure and overload) and physical (such as noise) stressors, so both must be considered when investigating stress. However, a limited number of studies have examined cognitive and physical interactions, but few have observed the interaction of stressors [8-10]. For example, Mehta and Parasuraman [11] reported that interference with the prefrontal cortex (PFC) affects motor activity during tasks requiring cognitive and physical processing. In addition, cumulative physical and psychological stress showed a significant increase in pulse and systolic blood pressure under hypoxic conditions, whereas individual psychological stress did not affect the same conditions [12].

The human brain has been the focus of study for many years to understand its role in the context of mental health and illness. This has contributed to the advancement of several neuroimaging modalities that can be divided into two distinct groups. One group measures the electrophysiological response of the brain and another group monitors hemodynamic changes associated with neural activity [13]. The former group includes EEG, transcranial magnetic stimulation (TMS), and magnetoencephalography (MEG), and the latter group comprises functional MRI, fNIRS, single-photon emission computed tomography (SPET), and positron emission tomography (PET). Each one of these modalities has its advantages and disadvantages. Compared to the latter category, the EEG provides excellent temporal resolution (less than milliseconds) but has low spatial resolutions [14, 15]. In contrast, the second class (fMRI, fNIRS, and PET) provides information on the location of the neural activation. Compared to fMRI and PET, fNIRS is smaller in size, has higher time resolution, is more portable, is less sensitive to motion artefacts, and offers relatively inexpensive and natural recording conditions [16, 17]. fNIRS provides information on changes in oxygenated and deoxygenated haemoglobin (HbO and HbR, respectively) levels. However, fMRI can only measure blood oxygen level (BOLD) responses related to HbR levels.

Despite the good involvement of individual modalities, only limited information is available on the association between neuronal activity and regional hemodynamic responses. Therefore, the two categories must be integrated to provide important information on the cortical function and neurovascular coupling in different mental functions. This integration combines the benefits of individual imaging techniques (e.g., a high spatial resolution of fMRI, fNIRS, and PET; a high temporal resolution of EEG) to maximize each benefit and minimize its limitations through different integration approaches.

The purpose of this research was to study the effects of noise level at work on mental stress using synchronized measurements of EEG and fNIRS. Two work environments with low and high noise levels in stressful mental conditions were investigated using the Montreal Imaging Stress Task (MIST) [18]. Besides, the relationship between noise levels in the workplace and cortical activation was assessed and their affected area localized. We hypothesized that a higher noise level would have a negative effect on the participant in terms of brain activity due to increased stress, which would be reflected in the concentration of HbO and EEG power.

## 2. Materials and Methods

### 2.1. Subjects
The study included 14 healthy participants (male; right-handed; mean age $28.7 \pm 2.6$ years) with no history of mental or neurological disorders. Each participant gave informed consent to his participation prior to the trials. This study was approved by the Medical Research Ethics Committee (MREC) of Universiti Kuala Lumpur Royal College of Medicine Perak (UniKL RCMP). All procedures were carried out in accordance with approved standards and guidelines.

### 2.2. Experiment Procedure
Participants undertook an experiment with overlapping physical and mental stressors, each with 30 s of a task and 20 s of rest. Physical stressors are two types of noise stimuli, one represents the low-noise level environment (~40-50 dB), and the other represents the high-noise level environment (~65-

75 dB). These types of stressors were randomly addressed using audio files that consisted of realistic sounds from the environment, such as people talking, moving furniture, and making phone calls. Psychological stressors were derived from negative feedback and lack of time in performing mental arithmetic tasks (MATs). These psychological stressors were combined into a single task, the Montreal Imaging Stress Task (MIST) [18]. The operators used in MAT computations were assigned randomly using the plus (+) and minus (-) operands (e.g., 12–15 + 9). MIST use has been attributed to its excellent performance in producing high stresses when tested with negative feedback at time pressure, as shown in previous studies [18-23].

Figure 1 shows the timeline and configuration of the experiment. During the habituation phase, participants were given a brief introduction and prepared to get used to the experimental environment. The MIST was performed in a periodic block design with five low and high- noise level blocks (30 s each) and followed by 20 s of rest (recovery condition). During the resting state, participants were encouraged to relax and concentrate on a fixation cross displayed in the centre of the monitor.
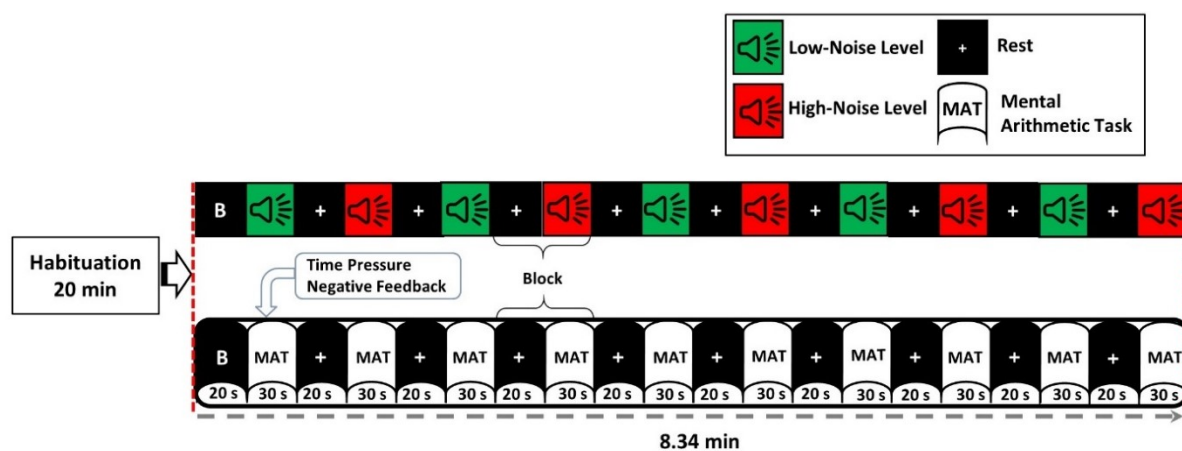


**Figure 1.** Experiment timeline of ten active blocks existed during stressful mental tasks in (a) low-noise level workplace; and (b) high-noise level workplace. Tasks for 30 s (mental stress) were obtained in each block, followed by 20 s of rest (recovery).  The onset and end of the task are indicated, respectively, by the red and green dashed lines.  The psychological stressors were time constraints and negative comments based on an individual's performance.

## 2.3. Signal Acquisition and Processing

In this study, EEG-fNIRS recordings were performed simultaneously. Custom probe holder with 17 EEG electrodes (Fpz, Fp2, Fp1, AF8, AF7, F8, F7, AFz, AF4, AF3, F6, F5, Fz, F2, F4, F1, and F3) and 24 fNIRS optodes (equivalent to 37 fNIRS channels) was designed according to the international 10/10 system (Figure 2). EEG data were collected using BrainMaster Discovery (BrainMaster Technologies Inc., Bedford, USA) with a sampling frequency of 256 Hz. The fNIRS system (OT-R40; two wavelengths: 695 and 830 nm; Hitachi Medical Corporation, Japan) was used to acquire the imaging data over the frontal regions with a sampling rate of 10 Hz.  All EEG electrodes were grounded at the Fz and referenced to the linked earlobes (A1 and A2) as highlighted in Figure 2. The electrodes' impedances were kept underneath 10 kΩ. The EEG and fNIRS data were pre-processed and analysed independently to obtain the desired output signal.
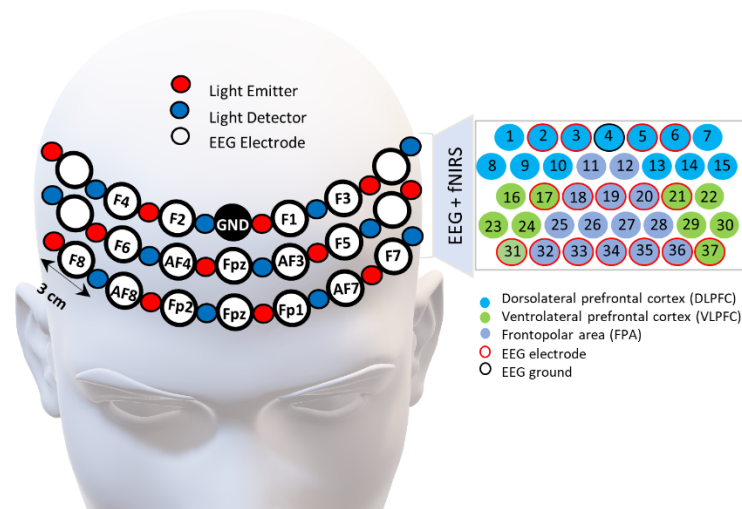
**Figure 2**. The graphical illustration of EEG and fNIRS probes according to the 10/10 system. The blue and red circles represent detectors and emitters of fNIRS, respectively, whereas white circles indicate the EEG electrodes. The integrated cap consists of 17 EEG electrodes and 37 channels of fNIRS were placed over bilateral frontal regions.

*2.3.1. EEG Signal Processing.* The data was initially filtered passband from 0.5 Hz to 70 Hz and then notched at 50Hz to reduce power line interference. Independent component analysis (ICA) was then performed to remove eye artefacts in the EEG signal. Baseline correction using pre-stimulation events was performed for each trial. The EEG data was then split to form epochs beginning 20 s before the start of the encoding phase and ending after 30 s. Finally, the EEG data was filtered into the delta, theta, alpha, and beta bands, namely 1-4 Hz, 4-8 Hz, 8-13Hz, and 13-30 Hz, respectively, using wavelet decomposition.

*2.3.2. fNIRS Signal Processing.* The Platform for Optical Topography Analysis Tool (POTATO) [24] was used along with MATLAB to examine fNIRS data. According to modified Beer-Lambert law, the raw density signal of near-infrared lights was first converted into changes in HbO and HbR concentrations [25]. Butterworth's fifth-order band-pass filter from 0.012 to 0.8 Hz was used to eliminate the effects of low-frequency oscillation and heartbeat. We performed baseline correction on each block by subtracting the average of the 20 s of rest condition from each of the data points of the task. All blocks were combined to obtain a single block of an averaged hemodynamic response.

*2.4. Statistical Analysis*

The $p$-values were calculated using the MATLAB paired t-test function (significant level $p < 0.05$) to examine the effects of noise level conditions ( low or high noise levels) on the severity of mental stress. The mean HbO signals were considered by the most significant channels to locate the most affected EEG electrodes. Post hoc analysis was determined by the Holm-Bonferroni test; differences in mean and standard error were revealed in this study.

**3. Results and Discussion**

In this study, we analyzed the effect of noise levels in the work environment on psychological stress by quantifying frontal lobe brain activity and hemodynamic responses. Working in a noisy environment is significantly associated with HbO deactivation in PFC. In this regard, participants who completed the MIST in high-noise environments had lower HbO concentrations and decreased alpha power than those in low noise environments. This study revealed the dissociation of the PFC subregion with respect to workplace noise levels during stressful mental tasks.

Topographic maps of the p-values of HbO during stress conditions in low and high noise environments are shown in Figure 3. At both workplaces, HbO concentrations in the right dorsolateral

PFC (DLPFC; CH2 and CH9) and part of the frontopolar area (FPA) were significantly decreased ($p <$ 0.05, paired t-test with Holm-Bonferroni corrected) in comparison with their baselines. These observations of dysfunction (reduction of HbO) under stress conditions are in direct agreement with previous findings [26-28]. Furthermore, our results confirm previous studies by [29] who identified that prolonged intermittent noises could affect the activation of HbO in the cortex of the PFC, particularly in some of the channels found in the DLPFC. This is also in line with a study by [30], who reported that some cognitive functions could be affected by ambient noise in healthy people and schizophrenic patients. In addition, the most significant interaction was observed in both workplaces with CH2 and CH9. These channels share the same position as the F4 EEG electrode according to our integrated cap configuration. We have therefore set the F4 electrode as the channel of interest for further analysis.
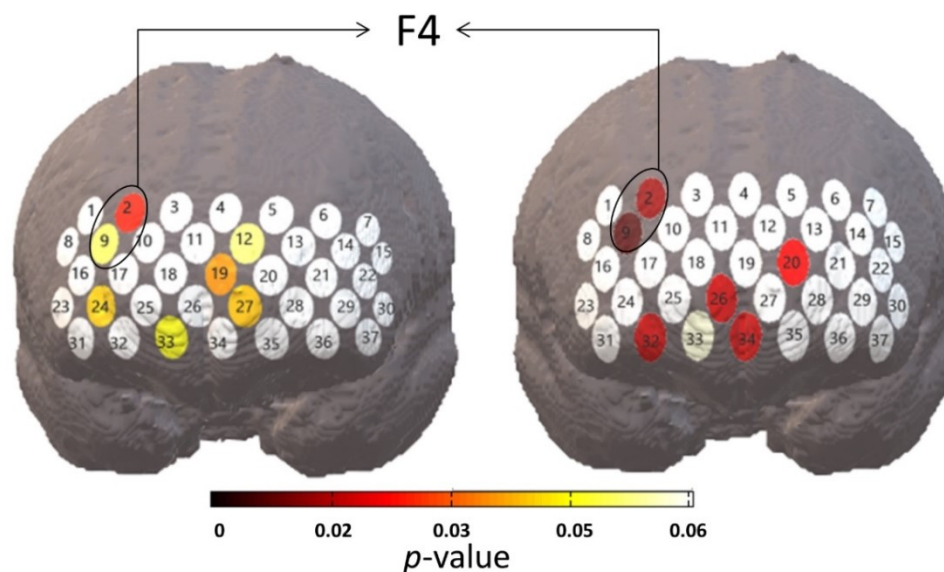


**Figure 3.** Cortical activation for group-level comparison between participants performing in low and high noise level workplaces during stressful conditions. The $p$-values are displayed based on the colour bar. Among the 37 channels placed in the PFC, significant mutual influence in both workplaces could be observed in CH2 and CH9.

Figure 4 shows the average power spectrum and standard error of the F4 channel for the two workplaces. The channel-mean delta and beta activities showed no difference in the mean values between baseline and stress conditions at both low and high workplaces (paired t-test Holm-Bonferroni corrected: delta, low-noise, $p = 0.96$, and high noise $p = 0.88$; beta, low-noise, $p = 0.58$, and high noise $p = 0.97$). However, there was a significant reduction in theta and beta power in a high-noise workplace compared to a low-noise workplace (paired t-test Holm-Bonferroni corrected: delta, $p < 0.001$ and beta, $p < 0.001$). Furthermore, alpha band power revealed significant differences when low and high noise level workplaces were compared with each other (paired t-test Holm-Bonferroni corrected: $p < 0.001$), and with their baselines (paired t-test Holm-Bonferroni corrected: alpha, low-noise, $p < 0.001$ and high-noise $p < 0.001$). No substantial differences in channel mean of theta power were observed when comparing high noise workplaces with baseline and low noise workplaces (paired t-test Holm-Bonferroni corrected: baseline, $p = 0.97$, and low-noise $p = 0.99$). However, there was a substantial decrease in the theta power during stress conditions in low noise level workplace as compared to the baseline (paired t-test Holm-Bonferroni corrected: $p < 0.001$).

Based on these findings, the alpha rhythm is more susceptible to psychological stress than other EEG rhythms. Furthermore, a good correlation can be observed between HbO and alpha power under stress conditions. According to the literature, EEG alpha power was associated with depression and stress conditions [31-35].
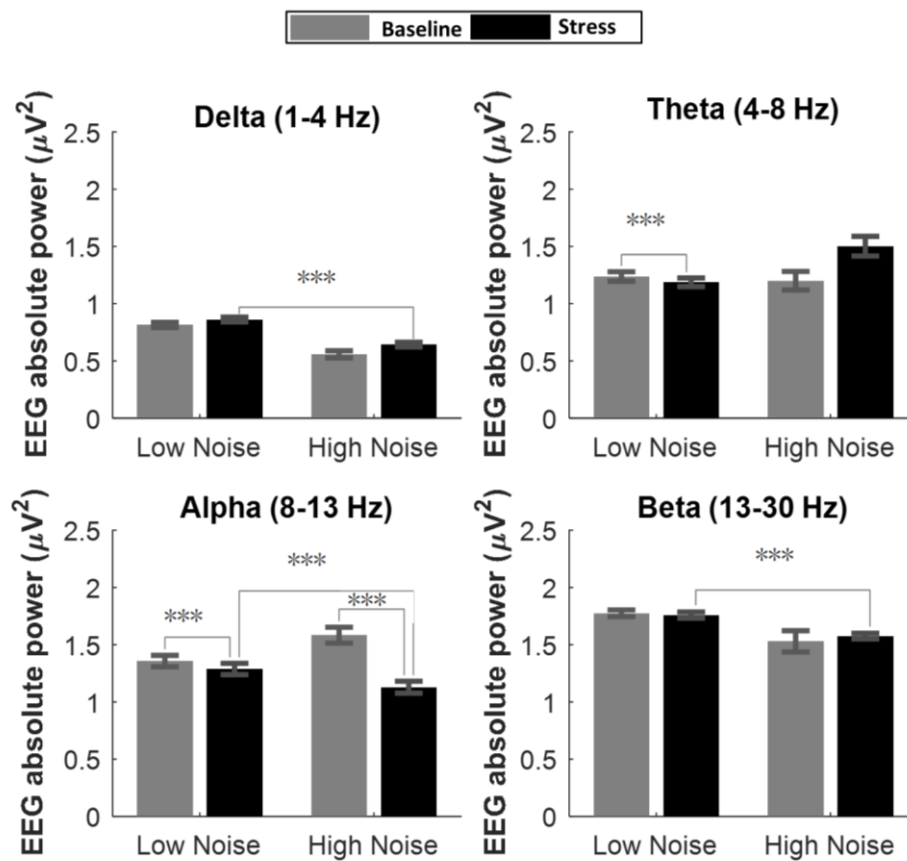
**Figure 4.** Comparison of the mean and the standard error of baseline and stress conditions for (a) Delta power, (b) Theta power, (c) Alpha power, and (d) Beta power; recorded by the right dorsolateral prefrontal channel F4 of fourteen subjects while performing MIST in low and high noise level workplaces. The black asterisks indicate the sample significantly (***$p < 0.001$, paired t-test Holm-Bonferroni corrected) and error bars indicate standard error.

## 4. Conclusion

In this study, we presented a study of the effect of high noise levels in the workplace on changes in brain activity associated with stress. The results showed that people working in high-noise workplaces were more prone to stress, as evidenced by a decrease in HbO concentration and EEG alpha power compared to those working in low-noise workplaces. The results also revealed that the effects of noise stress in the workplace were very localized in the right DLPFC. The findings of this study may contribute to a clear path for ways to manage stress in the workplace.

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