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Measurement of Individuals' Emotional Stress Responses to Construction Noise through Analysis of Human Brain Waves

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Abstract: Construction noise is among the most critical stressors that adversely affect the quality of life of the people residing near construction sites. Many countries strictly regulate construction noise based on sound pressure levels, as well as timeslots and type of construction equipment. However, individuals react differently to noise, and their tolerance to noise levels varies, which should be considered when regulating construction noise. Although studies have attempted to analyze individuals' stress responses to construction noise, the lack of quantitative methods to measure stress has limited our understanding of individuals' stress responses to noise. Therefore, the authors proposed a quantitative stress measurement framework with a wearable electroencephalogram (EEG) sensor to decipher human brain wave patterns caused by diverse construction stressors (e.g., worksite hazards). This present study extends this framework to investigate the feasibility of using the wearable EEG sensor to measure individuals' emotional stress responses to construction noise in a laboratory setting. EEG data were collected from three subjects exposed to different construction noises (e.g., tonal vs. impulsive noises, different sound pressure levels) recorded at real construction sites. Simultaneously, the subjects' perceived stress levels against these noises were measured. The results indicate that the wearable EEG sensor can help understand diverse individuals' stress responses to nearby construction noises. This research provides a more quantitative means for measuring the impact of the noise generated at a construction site on neighboring communities, which can help frame more reasonable construction noise regulations that consider various types of residents in urban areas.

Keywords: Construction Noise, Stress, Electroencephalogram (EEG), Brain waves

1. INTRODUCTION

Noise, which is defined as any type of unwanted and unpleasant sound, is one of the most critical stressors that adversely affect urban residents' physiological and psychological health, as well as their quality of life [1]. Especially, significant numbers of people residing near urban construction sites suffer from noise pollution produced by various sources during construction work, including equipment, machinery, tools, and traffic [2, 3]. Considering that high-frequency, high-intensity, and impulsive patterns, which are common in construction noise [1, 4], are the key physical characteristics of noise pollution, the noise pollution caused by construction sites should be well-managed in urban areas to mitigate its adverse effects on urban populations.

Therefore, many countries strictly regulate noise pollution based on the sound pressure level, which is commonly expressed as a weighted decibel (dBA), in addition to the time and duration of noise emission, source of noise (e.g., construction equipment types), and nature and characteristics of the locality (e.g., residential area). For example, according to the noise regulation guidelines provided by the International Organization for Standardization, in industrial areas, noise levels in the daytime and nighttime should be lower than 70 dBA and 60 dBA, respectively [5]. Stricter guidelines are applied to urban residential areas (e.g., lower than 45 dBA in the daytime and lower than 35 dBA in the nighttime). However, it has been found that individuals react differently to noises and have different levels of tolerance to noise. As such, the noise sensitivity of any individual affected by noise should be considered in formulating construction noise regulations. In this regard, many studies have attempted to analyze individually varying psychological responses (e.g., annoyance, stress) toward noise based on subjective ratings such as the Weinstein noise sensitivity index [6], and socio-acoustic surveys [7]. However, such self-assessments can include possible biases caused by the subjective rating scales. In addition, because of the time and effort required to gather survey ratings, it is difficult to apply the method on an ongoing basis to diverse sources of noise in different scenarios. The lack of quantitative methods to measure stress makes it difficult to fully understand individuals' stress responses to noise. In this regard, the authors had proposed a framework to quantitatively measure emotional stress by using a wearable electroencephalogram (EEG) sensor that can decipher the human brain wave patterns caused by diverse stressors at construction sites (e.g., worksite hazards) [8]. In this previous study, the authors measured two important emotional dimensions, namely, a valence dimension from displeasure to pleasure and an arousal dimension from not aroused to excited. Because negative emotions contribute critically to human stress and the valence dimension of emotion is closely associated with unpleasant feelings and the consequent annoyance and stress [9], the authors' previous framework can be useful for quantitatively measuring individuals' stress responses to construction noise. In the present study, the aforementioned framework is extended to investigate the feasibility of using the wearable EEG sensor to measure individuals' emotional stress responses to construction noises in the laboratory environment, where subjects are exposed to various construction noises recorded at real construction sites.

2. STRESS MEASUREMENT

2.1. Impact of Construction Noise

In the literature, it has been claimed that construction noise has many negative effects on urban residents, including emotional stress, annoyance, and distraction, which adversely affect the physical and emotional well-being of individuals [1]. More specifically, a high noise level is directly associated with individual annoyance accompanied by displeasure and emotional upset [10]. Moreover, high noise levels lead to heightened arousal, thereby affecting human attention and hindering sleep and relaxation [11, 12]. To sum up, the abovementioned effects of noise can be explained based on two important dimensions of emotions, valence and arousal. The valence dimension explains feelings of pleasure or displeasure (e.g., annoyance due to displeasure), while the arousal dimension explains relaxed and aroused states [13, 14]. These emotional valence and arousal dimensions can be employed as representative features to measure and classify stress levels, even though stress is a very complex psychological state [9, 15]. In this regard, in a previous work, the authors of this study demonstrated a feasible means to measure the emotional valence and arousal dimensions through an analysis of human brain waves related to emotional stress by collecting EEG signals with a wearable EEG sensor [8]. This measurement method that directly captures brain activity is expected to facilitate more reliable and continuous measurement of different individuals' emotional stress responses to construction noise, which can contribute to a more in-depth understanding of the effects of construction noise on urban residents. To this end, the feasibility of the EEG-based measurement of emotional stress responses to construction noise should be tested further, which is the main objective of the present study. The measurement method developed by Hwang et al. [8], is explained in the following section.

2.2. EEG-based Emotional Stress Measurement

Figure 1 shows the framework of EEG-based emotional stress measurement method proposed by Hwang et al. [8]. Because EEG signals are highly vulnerable to signal artifacts, the removal of such artifacts is a very important step in this study. The major objective of [8] was to measure construction workers' emotions by using wearable EEG sensors as they were working in the field, a scenario in which EEG signals are prone to considerably more signal artifacts. Before the research of [8], a framework for the removal of field EEG signal artifacts was proposed and successfully tested [16]. In the abovementioned study, EEG signals from 14 channels were collected and bandpass filters and notch filters were employed to remove significant extrinsic artifacts generated by external signal noise sources, such as electrode popping, movement artifacts, and wiring noise in the EEG sensor [8, 16]. Then, intrinsic artifacts such as signal noises due to blinking and movement of the eyes and movement of facial muscles were corrected by conducting an independent component analysis [8, 16].

After removal of the signal artifacts, power spectrum features (e.g., power spectral density: PSD) of the EEG signals were used to calculate the valence and arousal levels. A positive valence level (+) indicates a pleasant emotional state, while a negative valence level (-) indicates an unpleasant state. A positive arousal level (+) indicates an excited state, while a negative arousal level (-) indicates a relaxed state. This calculation was based on the PSD of the alpha and beta frequencies of the frontal lobe of the brain because the frontal lobe is associated with emotional control [8]. Based on this calculation, individuals' valence and arousal levels toward stressors, such as construction noise, can be determined.

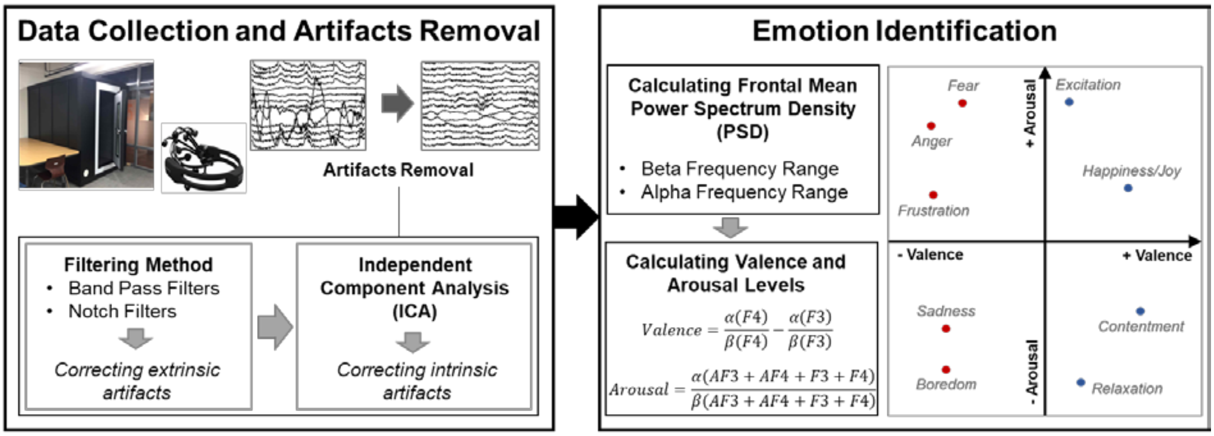


Figure 1. Framework of EEG-based emotional stress measurement

3. EXPERIMENTAL DESIGN

To investigate the feasibility of the EEG-based measurement of individuals' emotional stress responses to construction noise, we conducted a laboratory experiment. To generate construction noise stressors, the sounds made by construction equipment were recorded at a real construction site in which foundation work was in progress. Two different types of noise, namely, tonal and impulsive, were recorded from an earth auger and a pile driver, respectively. The noise of an earth auger is generally tonal while that of a pile driver is highly impulsive [5]. To produce various sound pressure levels, the recorded noises were adjusted to 40 dBA, 50 dBA, 60 dBA, 70 dBA, and 80 dBA.

In this experiment, three healthy subjects were recruited and exposed to a combination of two different construction noise types (i.e., steady and impulsive) at five sound pressure levels (i.e., 40 dBA, 50 dBA, 60 dBA, 70 dBA, and 80 dBA) inside an experimental auditory room over 10 sessions. During all sessions, subjects' EEG data were collected from the 14 channels of the wearable EEG sensor; each channel was operated at a sampling rate of 128 Hz. Each session lasted at least 5 min (i.e., more than 0.5 million data points in each session from 14 channels at the sampling rate of 128 Hz), and the subjects were allowed breaks of at least 10 min between sessions. The order of sessions was assigned randomly to minimize the order effect.

Because an individual's noise sensitivity can affect their emotional stress response [6], the subjects' noise sensitivities were measured using the 11-point personal noise sensitivity scale (from 0 to 10 points) before starting the experiment. In addition, the subjective level of emotional displeasure and annoyance toward each type of noise were surveyed using the 11-point annoyance scale (from 0 to 10 points) immediately after each session [7]. These subjective survey ratings were gathered to compare the subjects' emotional stress responses (i.e., valence and arousal levels) measured using the EEG signals with the subjects' perceived feelings of stress. Details of the subjects and the experimental protocol are summarized in Table 1.

Table 1. Subject information and experiment protocol

Subject Information				Experiment Protocol					
No.	**Age**	**Gender**	**Noise Sensitivity [0–10]**	**dBA / Noise Type**	**40**	**50**	**60**	**70**	**80**
1	25	Male	6	**Tonal (Earth auger)**	E40	E50	E60	E70	E80
2	23	Female	8						
3	24	Male	5	**Impulsive (Pile driver)**	P40	P50	P60	P70	P80

4. RESULTS AND ANALYSIS

Figure 2 shows all subjects' emotional stress responses in terms of the bipolar dimensions of valence and arousal levels based on their EEG signals. In this figure, the triangular labels indicate the subjects' responses to tonal construction sounds (i.e., sounds from an earth auger), while the circular labels indicate the subjects' responses to impulsive sounds (i.e., sounds from a pile driver). The darker labels indicate subjects' responses to higher sound pressure levels. The table inside Figure 2 describes the subjects' perceived annoyance (on a scale of 0 to 10) due to diverse noise stressors.

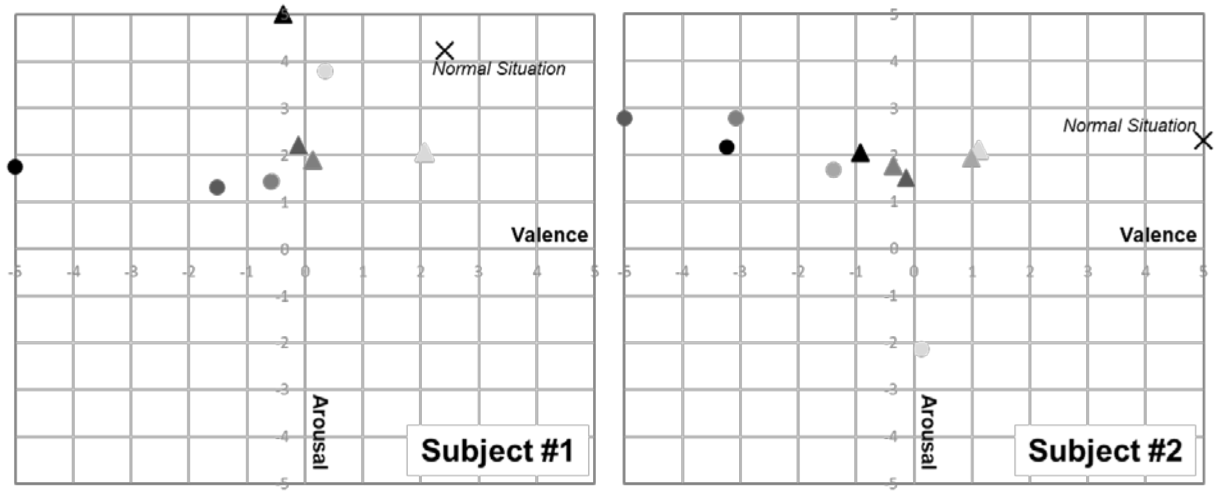
As can be seen in this figure, all subjects have lower valence levels (i.e., more negative valence levels and more unpleasant emotional states) when exposed to any type of construction noise stressors compared to those in normal settings ("X" labels in Figure 2) devoid of significant noise stressors. In addition, the subjects exhibit lower (more negative) valence levels and are consequently more likely to have considerable emotional stress in general in environments with loud noises at high sound pressure levels (dBA). Meanwhile, the perceived annoyance survey results given in the table in Figure 2 indicate the subjects' tendency of high annoyance scale scores in environments with loud noises.

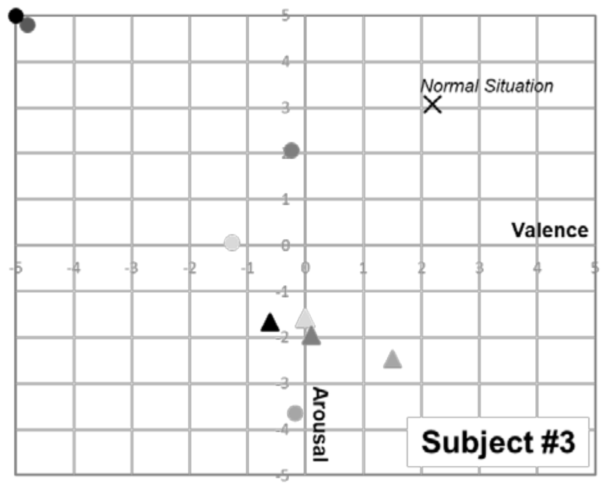
In addition, the subjects tended to have higher negative valence levels (i.e., more unpleasant emotions) under impulsive sounds compared to those under tonal sounds. The literature contains ample evidence supporting higher levels of personal annoyance under impulsive sounds owing to the highly fluctuating parameters of such sounds, which is consistent with the results obtained in the present study [7].

To summarize, significant changes in valence levels with sound pressure levels and noise types (i.e., tonal vs. impulsive) show the potential of the EEG-based method to measure individuals' emotional responses to noise stressors. Hwang et al. [8] demonstrated a significant correlation between negative valence levels and individuals' stress responses. Moreover, the annoyance scale, which is widely used to measure the effects of noise stressors on individuals' perceived feelings, is closely associated with feelings of displeasure and negative valence levels. Regardless of arousal levels, negative valence levels are linked to negative emotions, such as fear, anger, frustration, sadness, which affect individuals' stress levels. Therefore, valence level measurement can potentially be used to quantify urban residents' emotional stress responses to construction noise stressors.

Between the two dimensions of emotions, however, it is difficult to infer the impact of different noise stressors on subjects' arousal levels because of the possible effects of many uncontrollable factors on an individual's arousal levels (e.g., cognitive loads and distracting thoughts) and the small number of datasets. After confirming the results with a greater number of subjects, it is expected that the results of this study can be applied to devise more feasible construction noise regulations by considering the diverse features of noise sources and the stress responses of people residing in urban areas.

Notably, subject #2, who had the highest noise sensitivity levels, consistently showed negative valence levels with slightly positive arousal levels, even when exposed to low sound pressure levels. Although it is difficult to fully confirm the relationship between personal noise sensitivity and the EEG-based stress responses of the subjects in this study owing to the small sample size, the different emotional stress responses of individuals to construction noise imply that the differences should be considered when framing noise regulations to improve the quality of life of urban residents.





Sessions	Annoyance Scale [0 – 10]		
	Subject #1	Subject #2	Subject #3
E40	1	3	3
E50	2	5	4
E60	5	6	4
E70	8	8	5
E80	10	5	9
P40	1	8	3
P50	3	7	4
P60	3	6	4
P70	8	6	4
P80	9	9	9

Figure 2. EEG-based emotional stress and perceived annoyance toward construction noises

5. CONCLUSIONS AND FUTURE WORKS

In this study, the feasibility of EEG-based measurement of individuals' emotional stress responses to construction noises was examined by applying a framework for quantitative emotional stress measurement proposed by the authors in a previous study. The results show that an individual's valence levels measured with the wearable EEG sensor are closely associated with noise types and sound pressure levels, as well as the individual's perceived feeling of annoyance, which indicates the potential of using the wearable EEG sensor for determining diverse individuals' stress responses to noise from nearby construction sites. This research can contribute to providing a more quantitative means to measure the impact of construction noise on communities in the neighborhood. The outcomes of this research are expected to help devise more feasible construction noise regulations by considering various types of residents with different noise sensitivities in urban areas, as well as various noise sources in construction sites. Future research will further validate the EEG-based measurement of individuals' emotional stress responses to noise through additional laboratory and real-world experiments with larger numbers of subjects. Further measurement and validation are expected to provide an in-depth understanding of the impact of construction noise on diverse urban residents (e.g., people of different ages, different physical and psychological statuses) in different scenarios.

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