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Effects of Noise and Vibration Changes from Agricultural Machinery on Brain Stress Using EEG Measurement

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Abstract: In this study, the agricultural work stress induced by the noise and vibration of some agricultural machinery was analyzed through electroencephalogram (EEG) measurements. The values of spectral edge frequency (SEF) 95%, relative gamma power (RGP), and EEG-based working index (EWI), utilized as stress indicators, were derived by analyzing the EEG data collected. The EEG analysis revealed that agricultural work stress manifested when participants engaged in agricultural tasks following a period of rest. Additionally, the right prefrontal cortex was identified where the values of SEF95% and RGP increased concurrently with the rise in noise (61.42–88.39 dBA) and vibration (0.332–1.598 m/s^2). This study's results are expected to be utilized as foundational data to determine the agricultural work stress felt by farmers during work through EEG analysis in response to changes in noise and vibration.

Keywords: agricultural machine; electroencephalogram; stress; noise; vibration

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1. Introduction

Factors that induce agricultural work stress include harsh work environments, physical injuries, and agricultural machinery accidents [1,2]. Because agricultural machinery operates and performs agricultural work on fields and unpaved roads, workers are exposed to high noise and vibration levels from uneven road surfaces [3]. As noise and vibration significantly affect farmers' physical and mental stress, research is needed to reduce them [4,5]. Long-term exposure to noise and vibration causes physical and mental problems, such as reduced ability to think and concentrate, autonomic nervous system disturbances, increased discomfort, and cardiovascular diseases [6,7]. Noise and vibration can also directly cause communication problems, work errors, and safety accidents by indirectly causing the loss of attention and increased stress [8]. Detailed factors of noise that affect the psychology of workers include noise level, noise frequency characteristics, duration, noise level variation, and personal predictability for the occurrence of noise [9]. Among them, the noise level is the major factor that negatively impacts workers who work with machinery [10]. In a previous study that analyzed the effect of noise on humans, stress, concentration, and discomfort, indicators were evaluated with a survey [11]. Ke et al. [12] suggested that research is required to analyze the stress of test participants based on the noise level among detailed factors that determine the psychological effect of noise and that neurophysiological evaluation methods, such as analyzing the pattern of brain waves, will be effective. Studies that evaluated the stress and concentration of test participants in response to noise level changes through EEG analysis in areas other than agriculture are as follows. Kim and Park [13] conducted EEG analysis for skilled and unskilled drivers to identify changes in stress in response to the increased noise level

inside vehicles. They found that the power spectrum of beta waves measured from the temporal lobe increased as the noise level increased from 45 to 80 dBA. Ryu et al. [14] analyzed the effect of railway noise (70 and 80 dB) on the human body and found that the activation of beta waves at a noise level of 80 dB increased stress. Tassi et al. [15] conducted EEG analysis for test participants living near railways (39–41 dBA) and in quiet areas. They found that the test participants living near railways exhibited relatively higher power spectra of delta, alpha, and beta waves. Jee et al. [16] exposed car horn sound at a level of 101 dBA to test participants and found that alpha wave activity decreased and beta waves increased. Park et al. [17] evaluated the stress of test participants according to the presence or absence of subway noise. They found that the values of the delta and theta waves of the participants were relatively high in the absence of the noise, while the activity of alpha and beta waves increased in the presence of the noise. In a study by Ke et al. [18], the activity of beta and gamma waves measured in the left temporal lobe and the right prefrontal lobe was higher in the test participants exposed to a noise level of 80 dB than those without noise.

Regarding vibration, Song et al. [19] determined that vertical vibration must be considered first for evaluating ride vibration because it has a larger impact on ride comfort than horizontal vibration. Therefore, several studies were conducted to evaluate humans' physical stress in response to vertical vibration changes utilizing human body models or commercial software produced considering biomechanics [20,21]. However, research that evaluated mental stress is relatively insufficient. Studies that evaluated the mental effects of the vibration intensity, including the stress and alertness of test participants, through EEG analysis in areas other than agriculture are as follows. Landström and Lundström [22] conducted EEG analysis to analyze the alertness of test participants when they were exposed to a vibration intensity of 0.3 m/s^2. They found that the alertness effect occurred for the participants as the activity of alpha waves decreased and that of theta waves increased in the occipital lobe. Satou et al. [23] exposed a vertical vibration of 0.6 m/s^2 to test participants and evaluated the alertness of alpha waves. They found that the alertness of alpha waves was significantly different depending on the presence or absence of vertical vibration. In a follow-up study, they decreased the intensity of vertical vibration to 0.3 m/s^2 and analyzed the alertness of the alpha waves of test participants according to the frequency band (10 and 20 Hz) [24]. They found that the alertness of alpha waves was significantly different depending on the presence or absence of vertical vibration. However, there was no difference in the alertness of alpha waves depending on the frequency band. Min et al. [25] evaluated comfort according to the vibration intensity (0.315 and 1.0 m/s^2) to analyze the harmful psychological effect of vibration on the human body. It was found that there was no change in comfort according to the presence or absence of vibration under the 10 Hz and 0.315 m/s^2 conditions. However, exposure to the vibration of 10 Hz and 1.0 m/s^2 increased the discomfort of test participants as the activity of alpha waves measured from the left frontal lobe increased.

As described, studies in domains outside of agriculture have been conducted to assess stress based on biosignals, such as brainwaves. Conversely, in agriculture, evaluation methods primarily rely on surveys and observers to assess agricultural work stress [26,27]. These methods have limitations as they rely on the subjective opinions of participants or observers, resulting in qualitative rather than accurate and objective assessments of agricultural work stress [28].

In countries, including the United States, Europe, and South Korea, policies and related studies to alleviate the stress of farmers are supported by the judgment that stress reduces work efficiency and crop productivity [29–32]. If farmers' stress can be objectively evaluated and expressed in quantitative values, it will be possible to identify farmers excessively exposed to mental stress and provide appropriate assistance. Additionally, it can serve as an objective evaluation indicator in areas such as the ergonomic design of agricultural machinery.

The agricultural work stress experienced by farmers is different from the job stress of other job groups [33]. This is because the main factors that cause each group's stress are different. In addition, factors that affect agricultural work stress mainly occur outdoors and are multifactorial driven. Therefore, research on agricultural work stress evaluation is required based on different methods from the previous studies conducted indoors. In particular, noise and vibration inevitably occur during the operation of agricultural machinery. Therefore, it is necessary to analyze the effects of these stress factors on brain stress.

This study attempted to evaluate the effects of various environmental factors on agricultural work stress in agriculture. Agricultural work stress in response to noise and vibration changes was analyzed through EEG measurement for farmers who perform agricultural work with some agricultural machinery.

2. Materials and Methods

2.1. Design of Experiments

2.1.1. Structure and Function of the Brain [34]

Brainwaves are waveforms that record the potential difference generated during the transfer of neurotransmitters from the neurons that constitute the cerebral cortex [35]. The brain is divided into the prefrontal lobe, frontal lobe, temporal lobe, parietal lobe, and occipital lobe. The prefrontal lobe knows reality, determines work order, and is responsible for mental actions, such as problem-solving [36]. The frontal lobe makes decisions by analyzing the collected information, and it is mainly observed to determine the presence or absence of stress as it is highly active for emotional changes [37,38]. The parietal lobe integrates acquired information, including tactile, aural, and visual information [39]. The temporal lobe accepts aural information, and the occipital lobe accepts and interprets visual information [40]. Therefore, it is possible to identify cerebral areas activated in response to noise and vibration changes generated from agricultural machinery and the agricultural work stress felt by test participants by attaching electrodes that can measure EEG to these parts of the brain and analyzing the measured EEG.

2.1.2. EEG Measurement Test Method [34]

An EEG measurement test was conducted to derive agricultural work stress in response to changes in the noise and vibration generated from agricultural machinery during agricultural work. Seventeen farmers were selected as test participants. They were adult males aged 20 to 80 years old. For all of them, drinking, smoking, and taking medications were restricted from the day before the test. In addition, they had no history of neuropsychiatric orders. The participants were informed of the test method and possible risks before the EEG measurement test, and the test was conducted under the consent of the ethics committee and participants. In the test, EEG measurement was performed for 3 min while the participants were working and resting. In the working state, the participants performed actual agricultural work with various agricultural machines, such as tractors, transplanters, harvesters, and pest control machines. In the resting state, they rested on a chair without riding on agricultural machinery. The noise and vibration generated by agricultural machinery were measured in the working state.

2.1.3. EEG Measurement and Analysis [34]

The EEG measurement device and its specifications are illustrated in Figure 1 and Table 1. The EEG measurement device comprises electrodes, an analog-to-digital converter (ADC), and an amplifier [41]. The electrodes are attached to the scalp to measure the potential difference generated by the brain activity. The measured EEG is converted and amplified into an electrical signal (μV) through the ADC and amplifier and then transmitted wirelessly to the software for EEG analysis. A total of 20 electrodes were utilized for EEG measurement (Figure 2). Eighteen electrodes were attached to the prefrontal lobe (Fp1 and Fp2), frontal lobe (F3, F4, F7, F8, and Fz), temporal lobe (T3,

T4, T5, and T6), parietal lobe (P3, P4, Pz, C3, and C4), and occipital lobe (O1 and O2) considering the international 10–20 system [42]. The reference and ground electrodes were attached, considering the ipsilateral ear reference [35,43]. The reference electrode was attached to the right earlobe (A2). The ground electrode was attached to the left earlobe (A1). EEG signals were measured by setting the sampling rate to 500 Hz. Since the measured EEG was in the form of hybrid waves, it was classified into delta waves (0.5–4 Hz), theta waves (4–8 Hz), alpha waves (8–13 Hz), beta waves (13–30 Hz), and gamma waves (30–50 Hz) via fast Fourier transform analysis. As for the characteristics of each band, delta waves are activated in deep sleep or unconscious conditions [44]. Theta waves tend to increase in shallow sleep, deep rest, and creative thinking [45,46]. Alpha waves increase in rest conditions but decrease under certain stimuli [47]. Beta waves increase during decision-making owing to tension, concentration, and external stimuli [48,49]. Gamma waves tend to be activated when mental stress is caused by excitement, strong anxiety, and high cognitive burdens [50].

The stress of the test participants was evaluated by calculating the power intensity for each frequency band through power spectrum analysis [40,51]. Spectral edge frequency (SEF) 95%, relative gamma power (RGP), and the EEG-based working index (EWI) were utilized as indicators to represent the stress felt by the participants in the working state. The values of the indicators are proportional to the intensity of the agricultural work stress felt by the participants.

SEF95% is an indicator used to assess the stress perceived by participants by calculating the band-edge frequency corresponding to 95% in the power spectral density within the 0.5–50 Hz range. Consequently, the agricultural work stress encountered by the participants can be considered higher with an increase in the SEF95% value [52]. RGP and EWI are computed through Equations (1) and (2), respectively [50,53].

$$R_\gamma = \frac{PS_\gamma}{PS_\delta + PS_\theta + PS_\alpha + PS_\beta + PS_\gamma} \quad (1)$$

where

RGP = relative gamma power
PS_δ = power spectrum of delta waves, μV^2
PS_θ = power spectrum of theta waves, μV^2
PS_α = power spectrum of alpha waves, μV^2
PS_β = power spectrum of beta waves, μV^2
PS_γ = power spectrum of gamma waves, μV^2

$$WI = \frac{PS_\beta + PS_\gamma}{PS_\theta + PS_\alpha} \quad (2)$$

An independent sample *t*-test was conducted to examine whether there were significant differences in the values of SEF95%, RGP, and EWI when the participants performed work after rest. In this instance, the agricultural work stress indicators (SEF95%, RGP, and EWI) derived through EEG measurement with 18 electrodes except for the reference and ground electrodes were dependent variables, while the resting and working states were independent variables. This process identified whether the participants felt agricultural work stress when they performed agricultural work by operating various agricultural machines. Statistical Package for the Social Sciences software (SPSS, Version 26, IBM Corp., Armonk, NY, USA) was utilized for all statistical analyses conducted here.

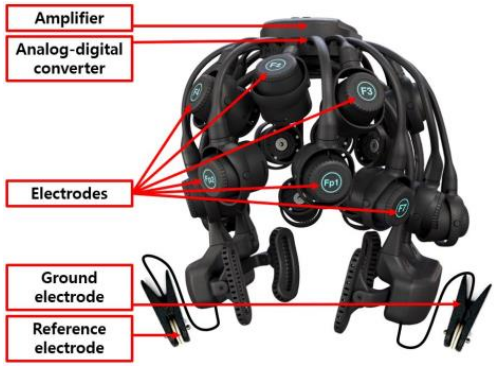

Figure 1. Shape of the EEG measurement device used.

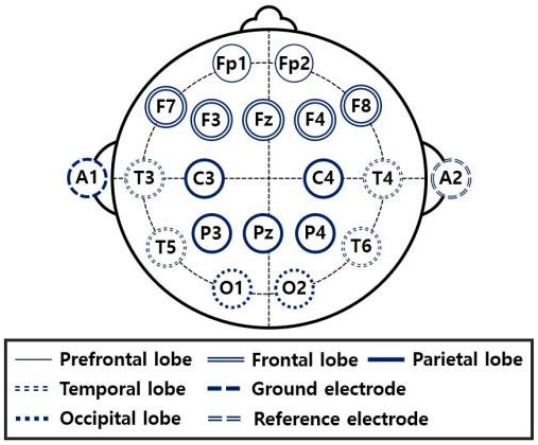

Figure 2. Attachment location of electrodes for the EEG measurement.

Table 1. Specifications of the EEG measurement device used.

Items	Specification
Model/Company/Nation	Quick-20r/CGX/USA
Weight (g)	596
Number of electrodes	20
Sampling rate (samples/s)	500
Bandwidth (Hz)	0–131
A/D Resolution (bit)	24
Wireless range (mm)	10,000

2.1.4. Noise Measurement and Analysis

The noise felt by the participants was measured and analyzed considering ISO 1996-1 (2016), the representative international standard for noise evaluation. The noise measurement position was set to a horizontal distance of 50–100 mm from the ear of each participant at the same height by referring to the literature and ISO 1996-1 regulations [10,54,55].

In addition, farmers' stress changes in response to noise changes were analyzed through the equivalent noise level (L_{Aeq}) that applied correction value A based on the 1/3 octave band [56]. The noise measurement frequency range was set to 25–8000 Hz, considering the noise measurement standard [57]. The noise was measured for 3 min. The sound level meter utilized and its position and specifications are presented in Figures 3 and 4 and Table 2.



Figure 3. The sound level meter utilized.



Figure 4. Layout of noise measurement.

Table 2. Specifications of the sound level meter utilized.

Items		Specification
Model/Company/Nation		NL-42/RION/Japan
Length × Width × Height (mm)		250 × 76 × 33
Weight (g)		400
Frequency range (Hz)		20–8000
Measurement range (dB)	A-weighting	25–138
	C-weighting	33–138
	Z-weighting	38–138
Inherent noise (dB)	A-weighting	≤17
	C-weighting	≤25
	Z-weighting	≤30

Simple regression analysis was conducted to examine whether the agricultural work stress of the participants exhibited a significant difference depending on noise when they performed work. In the simple regression analysis, SEF95%, RGP, and EWI were set as dependent variables and the equivalent noise level as independent variables.

To represent changes in the participants' agricultural work stress owing to noise, the equivalent noise level measured in the 61.42–88.39 dBA range was classified and grouped into three levels (60–70 dBA, 70–80 dBA, and 80–90 dBA). The SEF95%, RGP, and EWI values of the participants in each group were then expressed and averaged in time-series data. To increase the visibility of the graph, the SEF95%, RGP, and EWI values analyzed every second were converted into a z-score with a value between zero and one [35,58]. The moving average expressed in the graph was derived based on 20 samples.

2.1.5. Vibration Measurement and Analysis

The vibration experienced by the participants was measured and analyzed in accordance with ISO 2631-1 (1997), the international standard for assessing full-body vibra-

tion [59]. Adhering to ISO 2631-1 regulations, the probe for vibration measurement was positioned at the bottom of the driver's seat for riding-type agricultural machines (such as tractors, fertilizer applicators, combines, and rice planters) and at the handle for walking-type agricultural machines (e.g., a vegetable planter) [59]. Vertical vibration, expressed in acceleration (m/s^2) based on each participant's body, was measured over a three-minute duration. The vibrometer used and its specifications are detailed in Figures 5 and 6 and Table 3. The root mean square (RMS) value of the measured vibration was employed as the representative measure of the ride vibration experienced during the agricultural work process [56,60,61]. A simple regression analysis was conducted to investigate whether participants' agricultural work stress exhibited a significant difference based on the vibration experienced during their tasks. In this analysis, SEF95%, RGP, and EWI were designated as dependent variables, with the RMS value of vibration considered the independent variable.



Figure 5. The vibrometer utilized.



Figure 6. Layout of the vibration measurement.

Table 3. Specifications of the vibrometer utilized.

Items		Specification
Model/Company/Nation		VA-12/RION/Japan
Length × Width × Height (mm)		214 × 105 × 36
Weight (g)		850
Measurement frequency range (Hz)	Acceleration	1–20,000
	Velocity	3–3000
	Displacement	3–500
Measurement range	Acceleration (m/s^2)	0.02–141.4
	Velocity (mm/s)	0.2–141.4
	Displacement (mm)	0.02–40
Inherent noise	Acceleration (m/s^2)	≤0.01
	Velocity (mm/s)	≤0.1
	Displacement (mm)	≤0.01

To represent changes in the agricultural work stress of the participants due to vibration, the vibration measured in the 0.332–1.598 m/s^2 range was classified and grouped into three levels (0.315–0.630 m/s^2, 0.630–0.900 m/s^2, and 0.900–1.600 m/s^2). The SEF95%, RGP, and EWI values of the participants in each group were then expressed and averaged in time-series data. To increase the visibility of the graph, the SEF95%, RGP, and EWI values analyzed every second were converted into a z-score with a value between zero and one [35,58]. The moving average expressed in the graph was derived based on 20 samples.

3. Results and Discussion

3.1. Result of EEG Analysis According to the Resting and Working State

3.1.1. SEF95% According to the Resting and Working State

A *t*-test was conducted to examine whether the SEF95% indicator exhibited a significant difference when the participants performed agricultural work after rest. The *t*-test results revealed that the SEF95% value indicated a significant difference (* $p < 0.05$) at the prefrontal lobe (Fp2) and frontal lobe (F8) among the 18 electrode positions depending on the state and that it increased in the working state (Table 4). At the prefrontal lobe (Fp2) electrode position, the SEF95% value increased by 5.78% in the working state compared to the resting state. It also increased by 11.36% at the frontal lobe (F8) electrode position when the resting state changed to the working state. This confirmed the occurrence of the agricultural work stress of the participants in the working state. The SEF95% values derived from other electrodes revealed no significant difference depending on the state at the 5% significance level. At the Fp2 and F8 positions, brainwaves in the high-frequency band appeared activated as the participants' stress increased when they performed agricultural work after rest.

Table 4. T-test result based on the SEF95% in response to resting and working states ($p < 0.05$).

EEG Electrode Position		State	N	Mean	Standard Deviation	t (*p*)
Prefrontal lobe	Fp2	Rest Work	51 51	37.014 39.155	3.742 5.203	−2.386 (0.019)
Frontal lobe	F8	Rest Work	51 51	35.842 39.915	4.635 3.388	−5.066 (0.000)

3.1.2. RGP According to the Resting and Working States

A *t*-test was conducted to examine whether the RGP indicator revealed a significant difference when the participants performed agricultural work after rest. The *t*-test results indicated that the RGP values measured from the right prefrontal lobe (Fp2) and right frontal lobe (F8) exhibited a significant difference (* $p < 0.05$) and that they increased in the working state (Table 5).

Table 5. T-test result based on RGP in response to resting and working states ($p < 0.05$).

EEG Electrode Position		State	N	Mean	Standard Deviation	t (*p*)
Prefrontal lobe	Fp2	Rest Work	51 51	0.100 0.127	0.037 0.048	−3.186 (0.002)
Frontal lobe	F8	Rest Work	51 51	0.093 0.113	0.047 0.048	−2.209 (0.029)

The RGP value of the participants measured at the Fp2 electrode position increased by 27% in the working state compared to the resting state. It also increased by 21.51% at the F8 electrode position when the resting state changed to the working state. This confirmed the occurrence of the agricultural work stress of the participants in the working

state. This indicates that the power spectral density of gamma waves increased in the working state as the participants performed high-level cognitive functions, such as the recognition, perception, and integration of information [50]. The RGP values derived from other electrodes revealed no significant difference depending on the state at the 5% significance level.

3.1.3. EWI According to Resting and Working States

A *t*-test was conducted to examine whether the EWI indicator exhibited a significant difference when the participants performed agricultural work after rest. In the *t*-test results, the EWI value exhibited a significant difference (* $p < 0.05$) at the parietal lobe (P3, P4, and Pz), temporal lobe (T5 and T6), and occipital lobe (O1 and O2) among the 18 electrode positions depending on the state (Table 6). This indicates that theta and alpha waves were more dominant than beta and gamma waves for the participants in the resting state. However, the activity of beta and gamma waves increased and that of theta and alpha waves relatively decreased when they performed agricultural work.

Table 6. T-test result based on EWI in response to resting and working states ($p < 0.05$).

EEG Electrode Position		State	N	Mean	Standard Deviation	t (*p*)
Parietal lobe	P3	Rest	51	1.273	0.429	−3.459 (0.001)
		Work	51	1.637	0.617	
	P4	Rest	51	1.212	0.447	−3.556 (0.001)
		Work	51	1.585	0.602	
	Pz	Rest	51	1.132	0.341	−2.993 (0.003)
		Work	51	1.446	0.667	
Temporal lobe	T5	Rest	51	1.272	0.495	−3.054 (0.003)
		Work	51	1.740	0.975	
	T6	Rest	51	1.187	0.424	−2.086 (0.040)
		Work	51	1.444	0.769	
Occipital lobe	O1	Rest	51	1.141	0.430	−2.919 (0.004)
		Work	51	1.464	0.662	
	O2	Rest	51	1.138	0.425	−2.712 (0.008)
		Work	51	1.445	0.687	

The EWI value of the participants measured at the T5 electrode position increased by 36.79% in the working state compared to the resting state, indicating the highest increase rate among the electrodes that exhibited a significant difference. P4 indicated the second highest EWI value increase rate (30.78%), followed by P3 (28.59%), O1 (28.3%), Pz (27.74%), O2 (26.97%), and T6 (21.65%). The EWI values derived from other electrodes revealed no significant difference depending on the state at the 5% significance level.

3.2. Result of EEG Analysis According to Noise Changes

3.2.1. SEF95% Value According to Noise Changes

When simple regression analysis was conducted to examine whether the SEF95% indicator exhibited a significant difference depending on noise in the working state, the SEF95% values measured from the prefrontal lobe (Fp1 and Fp2) and frontal lobe (F3) indicated a significant difference (* $p < 0.05$) depending on noise. Table 7 shows the unstandardized coefficients (*B*), standard errors (*S.E.*), standardized coefficients (β), T-value (t), *p*-value (*p*), and the coefficient of determination (R^2) of the independent variable and constant derived from the simple linear regression analysis.

Table 7. Result of simple regression analysis based on the SEF95% in response to noise changes ($p < 0.05$).

Dependent Variable		Independent Variable	*B*	*S.E.*	β	t	*p*	R^2
Prefrontal lobe	Fp1	constant	−8.406	9.000	-	−0.934	0.355	0.359
		noise (L_{Aeq})	0.606	0.116	0.599	5.241	0.000	
	Fp2	constant	−2.717	8.187	-	−0.332	0.741	0.349
		noise (L_{Aeq})	0.539	0.105	0.591	5.128	0.000	
Frontal lobe	F3	constant	2.353	12.321	-	0.191	0.849	0.135
		noise (L_{Aeq})	0.437	0.158	0.367	2.763	0.008	

In addition, the regression coefficients of SEF95% measured at the Fp1, Fp2, and F3 positions exhibited positive correlations with values of 0.606, 0.539, and 0.437, respectively, and the SEF95% value increased as noise increased. The SEF95% values derived from other electrodes revealed no significant difference depending on the noise change at the 5% significance level.

When the equivalent noise level exceeded 40 dBA, the brainwaves of the participants responded. It has been determined that the SEF95% value increases with noise intensity because brainwaves in high-frequency bands are activated in the prefrontal lobe and frontal lobe, which are sensitive to emotional changes, such as stress. Moreover, the sympathetic nervous system is activated as the center of the autonomic nervous system in the hypothalamus is stimulated, leading to the secretion of both adrenaline and norepinephrine, stress hormones, by the adrenal cortex [62]. This mechanism enhances concentration, cognitive functions, long-term memory, and working memory in the prefrontal lobe.

The SEF95% values measured from the left prefrontal lobe (Fp1) and left frontal lobe (F3) revealed no significant difference depending on the state (Table 4). Therefore, it will be possible to evaluate agricultural work stress in response to noise changes if SEF95% is evaluated by analyzing the EEG measured from the right prefrontal lobe (Fp2).

Figure 7 shows variations in SEF95% at the prefrontal lobe (Fp1 and Fp2) and frontal lobe (F3) for the three groups classified based on the degree of the human body response corresponding to equivalent noise levels (60–70 dBA, 70–80 dBA, and 80–90 dBA).

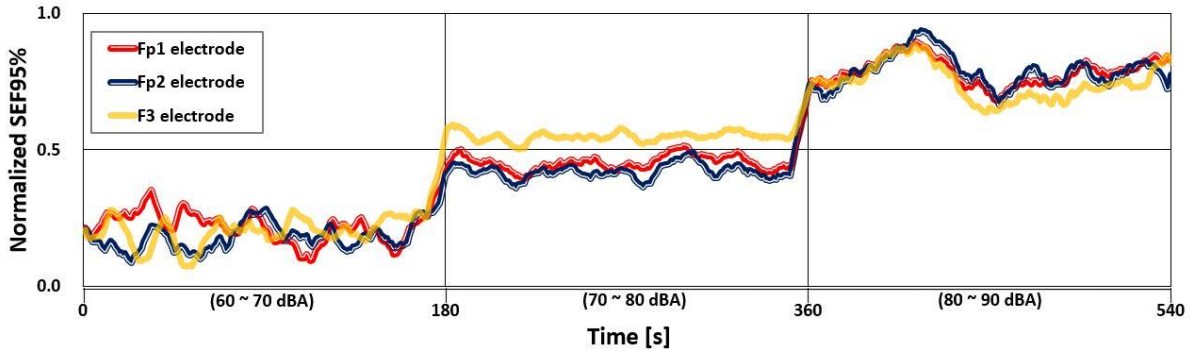

Figure 7. Variations in the SEF95% in response to noise changes.

3.2.2. RGP Value According to Noise Changes

Simple regression analysis was conducted to examine whether the RGP indicator revealed a significant difference depending on noise in the working state. In the analysis results, the RGP values measured from the prefrontal lobe (Fp1 and Fp2) and frontal lobe (F3) revealed a difference depending on noise at the 5% significance level (Table 8). In addition, the regression coefficients of RGP measured at the Fp1, Fp2, and F3 positions exhibited positive correlations with values of 0.006, 0.006, and 0.004, respectively, indicating that the RGP value increased as noise increased. The RGP values derived from other electrodes revealed no significant difference depending on the noise change.

Table 8. Result of simple regression analysis based on RGP in response to noise changes ($p < 0.05$).

Dependent Variable		Independent Variable	*B*	*S.E.*	β	t	*p*	R^2
Prefrontal lobe	Fp1	constant	−0.310	0.082	-	−3.800	0.000	0.361
		noise (L_{Aeq})	0.006	0.001	0.601	5.257	0.000	
	Fp2	constant	−0.302	0.071	-	−4.250	0.000	0.428
		noise (L_{Aeq})	0.006	0.001	0.654	6.053	0.000	
Frontal lobe	F3	constant	−0.201	0.096	-	−2.090	0.042	0.167
		noise (L_{Aeq})	0.004	0.001	0.409	3.139	0.003	

It is determined that the activity of gamma waves increased at the prefrontal lobe and frontal lobe, which sensitively respond to emotional changes, as the intensity of the noise generated from agricultural machinery and surrounding environment increased in the working state because the agricultural work stress felt by the participants increased. Considering that the RGP values measured from the left prefrontal lobe (Fp1) and left frontal lobe (F3) indicated no significant difference depending on the state in Table 5, it will be possible to evaluate agricultural work stress in response to noise changes if RGP is derived by analyzing the EEG measured from the right prefrontal lobe (Fp2).

Figure 8 presents variations in RGP at the prefrontal lobe (Fp1 and Fp2) and frontal lobe (F3) for the three groups classified based on the degree of the human body response corresponding to equivalent noise levels (60–70 dBA, 70–80 dBA, and 80–90 dBA).

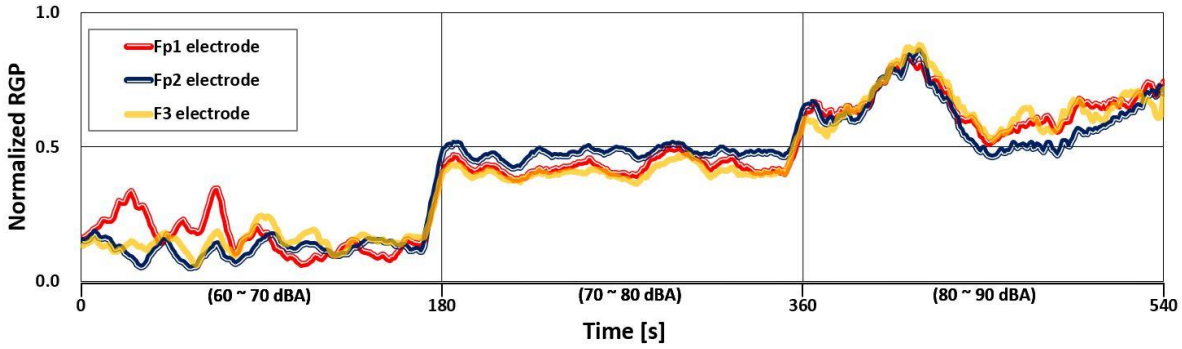

Figure 8. Variations in RGP in response to noise changes.

3.2.3. EWI Value According to Noise Changes

Simple regression analysis was conducted to determine if there was a significant difference in the EWI indicator based on noise in the working state. The analysis results showed that the EWI values measured from the prefrontal lobe (Fp1 and Fp2), frontal lobe (F3 and F4), and parietal lobe (Pz) all showed a significant difference (* $p < 0.05$) depending on noise (Table 9). Additionally, the regression coefficients of EWI measured at the Fp1, Fp2, F3, F4, and Pz positions were positively correlated with values of 0.064, 0.063, 0.032, 0.032, and 0.036, respectively, indicating that the EWI value increased with an increase in noise. On the other hand, the EWI values obtained from other electrodes did not show a significant difference based on changes in noise.

Figure 9 compares RTP, RAP, RBP, and RGP among three groups classified based on the degree of human body response according to the equivalent noise level (60–70 Dba, 70–80 Dba, and 80–90 Dba). The RGP and RBP, derived from the prefrontal lobe (Fp1 and Fp2), right frontal lobe (F3), and parietal lobe (Pz), gradually increased as the noise intensity increased. However, RTP and RAP either decreased or indicated a relatively low rate of increase. For the prefrontal lobe (Fp1 and Fp2) and frontal lobe (F3 and F4), there was no significant difference (* $p < 0.05$) depending on the state (Table 6). This indicates that the Pz position of the parietal lobe is an effective measurement position for evaluating agricultural work stress caused by noise using the EWI indicator. The parietal lobe, which

comprises a somatosensory area and motor area and integrates acquired information, such as aural, visual, and tactile information, demonstrated a significant response to noise. Beta and gamma waves also appear to increase as noise increases because they are activated in response to tension, concentration, external stimuli, or when high-level cognitive functions are performed. However, the activity of theta and alpha waves, which are activated in psychologically stable conditions (e.g., rest and sleep), either decreased or increased at a lower rate compared to the increase in noise intensity.

Table 9. Result of simple regression analysis based on EWI in response to noise changes ($p < 0.05$).

Dependent Variable		Independent Variable	*B*	*S.E.*	β	t	*p*	R^2
Prefrontal lobe	Fp1	constant	−3.585	1.186	-	−3.024	0.004	0.263
		noise (L_{Aeq})	0.064	0.015	0.513	4.184	0.000	
	Fp2	constant	−3.549	1.143	-	−3.104	0.003	0.273
		noise (L_{Aeq})	0.063	0.015	0.522	4.285	0.000	
Frontal lobe	F3	constant	−1.327	0.914	-	−1.452	0.153	0.134
		noise (L_{Aeq})	0.032	0.012	0.366	2.754	0.008	
	F4	constant	−1.325	0.956	-	−1.386	0.172	0.121
		noise (L_{Aeq})	0.032	0.012	0.348	2.600	0.012	
Parietal lobe	Pz	constant	−1.351	1.237	-	−1.092	0.280	0.095
		noise (L_{Aeq})	0.036	0.016	0.308	2.266	0.028	

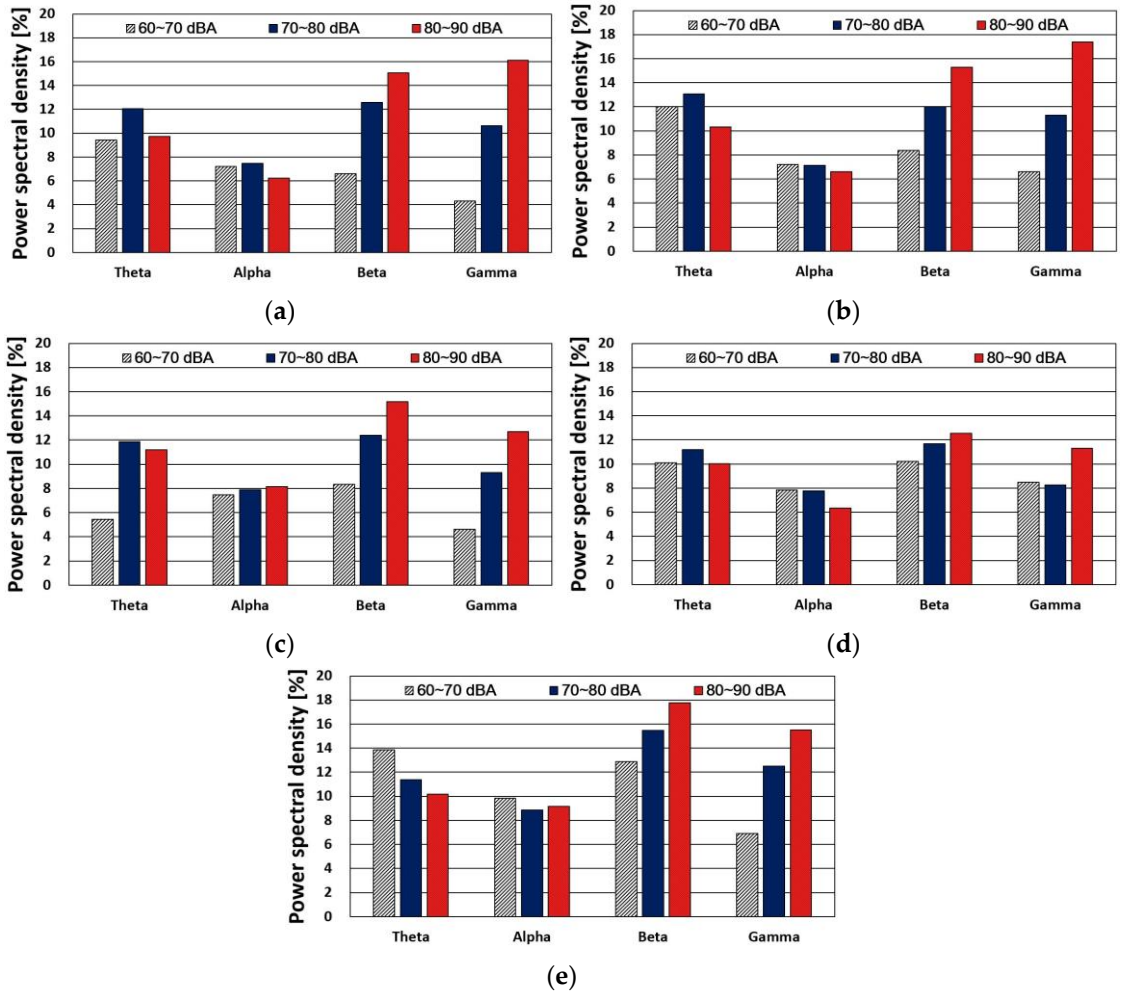

Figure 9. RTP, RAP, RBP, and RGP values for each electrode in response to noise changes. (**a**) Fp1 electrode; (**b**) Fp2 electrode; (**c**) F3 electrode; (**d**) F4 electrode; (**e**) Pz electrode.

Figure 10 shows variations in EWI at the prefrontal lobe (Fp1 and Fp2), frontal lobe (F3 and F4), and parietal lobe (Pz) for the three groups classified based on the degree of the human body response corresponding to equivalent noise levels (60–70 Dba, 70–80 Dba, and 80–90 Dba).

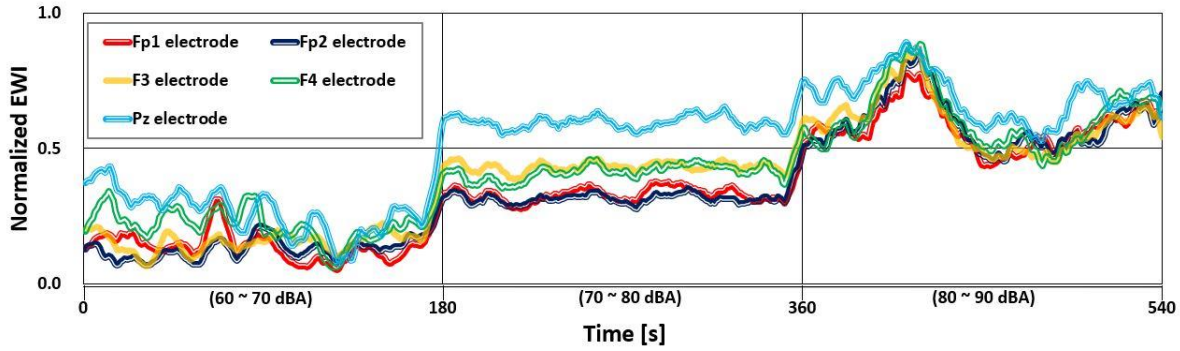

Figure 10. Variations in EWI in response to noise changes.

3.3. Result of EEG Analysis According to Vibration Changes

3.3.1. SEF95% Value According to Vibration Changes

Simple regression analysis examined whether the SEF95% indicator significantly differed depending on vibration during agricultural work. The SEF95% values measured from the prefrontal lobe (Fp1 and Fp2) exhibited a significant difference (* $p < 0.05$) depending on vibration (Table 10). In addition, the regression coefficients of SEF95% measured at the Fp1 and Fp2 positions exhibited positive correlations with values of 9.569 and 7.409, respectively, and the SEF95% value increased as vibration increased. The SEF95% values derived from other electrodes revealed no significant difference depending on the vibration change at the 5% significance level.

Table 10. Result of the simple regression analysis based on the SEF95% in response to vibration changes ($p < 0.05$).

Dependent Variable		Independent Variable	*B*	*S.E.*	β	t	*p*	R^2
Prefrontal lobe	Fp1	constant	30.002	2.147	-	13.976	0.000	0.270
		Vibration (a_{rms})	9.565	2.249	0.519	4.252	0.000	
	Fp2	constant	32.664	1.756	-	18.603	0.000	0.249
		Vibration (a_{rms})	7.409	1.840	0.499	4.027	0.000	

When vibration is detected by receptors, such as Pacinian corpuscles and Meissner corpuscles, the somatosensory area of the parietal lobe integrates information and generates discomfort [56]. It was determined that the SEF95% value increased as vibration intensity increased because brainwaves in high-frequency bands were activated in the prefrontal lobe (Fp1 and Fp2), which sensitively responds to emotional changes, such as stress. Considering that the SEF95% value indicated no significant difference (* $p < 0.05$) depending on the state in the left prefrontal lobe (Fp1), the right prefrontal lobe (Fp2) will be an effective measurement position for evaluating the agricultural work stress in response to the vibration change utilizing the SEF95% indicator.

Figure 11 presents variations in SEF95% at the prefrontal lobe (Fp1 and Fp2) for the three groups classified based on the RMS of vibration (0.315–0.630 m/s^2, 0.630–0.900 m/s^2, and 0.900–1.600 m/s^2).

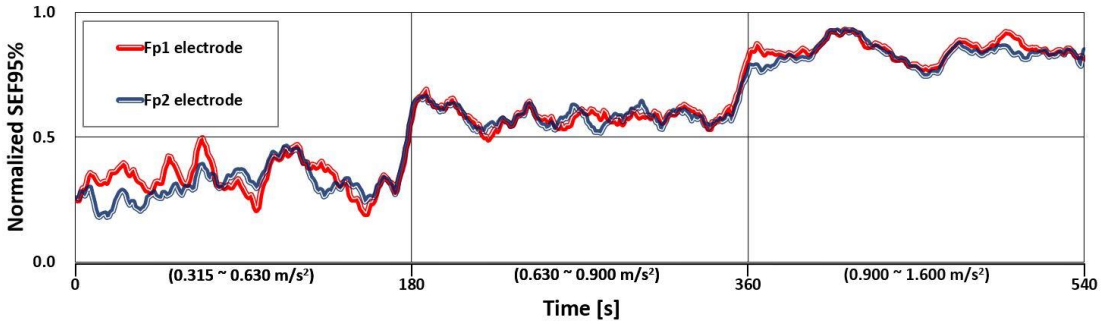

Figure 11. Variations in SEF95% in response to vibration changes.

3.3.2. RGP Value According to Vibration Changes

Simple regression analysis was conducted to examine whether the RGP value indicated a significant difference depending on vibration in the working state. In the simple regression analysis results, the RGP values measured from the prefrontal lobe (Fp1 and Fp2) differed depending on vibration at the 5% significance level (Table 11). The regression coefficients of RGP measured at the Fp1 and Fp2 positions indicated positive correlations with values of 0.093 and 0.101, respectively, indicating that the RGP value increased as vibration increased.

Table 11. Result of simple regression analysis based on RGP in response to vibration changes ($p < 0.05$).

Dependent Variable		Independent Variable	*B*	*S.E.*	β	t	*p*	R^2
Prefrontal lobe	Fp1	constant	0.034	0.019	-	1.782	0.081	0.310
		Vibration (a_{rms})	0.093	0.020	0.556	4.688	0.000	
	Fp2	constant	0.035	0.016	-	2.236	0.030	0.435
		Vibration (a_{rms})	0.101	0.017	0.660	6.146	0.000	

The RGP values derived from other electrodes revealed no significant difference depending on the vibration change at the 5% significance level.

It was determined that the activity of gamma waves increased at the prefrontal lobe and frontal lobe, which sensitively respond to emotional changes, as the intensity of the noise generated from agricultural machinery and the surrounding environment increased in the working state because the agricultural work stress felt by the participants increased. Considering that the RGP value revealed no significant difference (* $p < 0.05$) depending on the state in the left prefrontal lobe (Fp1), the right prefrontal lobe (Fp2) will be an effective measurement position for evaluating the agricultural work stress in response to the vibration change utilizing the RGP indicator.

Figure 12 presents variations in RGP at the prefrontal lobe (Fp1 and Fp2) for the three groups classified based on the RMS of vibration (0.315–0.630 m/s^2, 0.630–0.900 m/s^2, and 0.900–1.600 m/s^2).

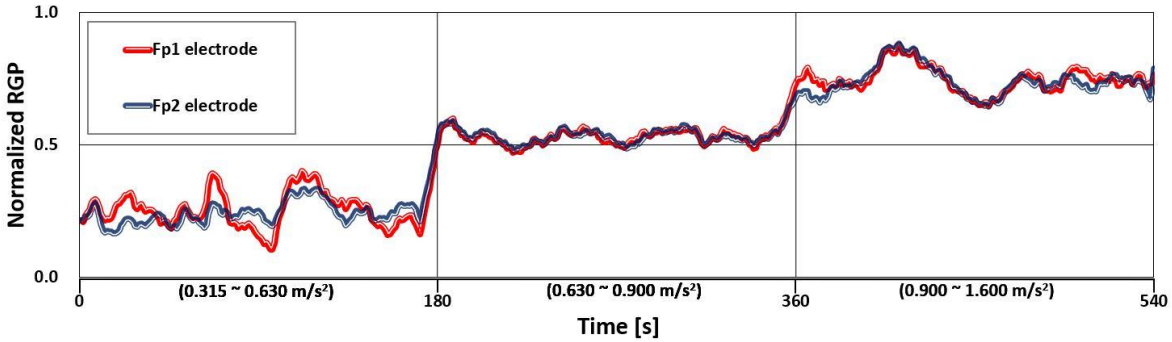

Figure 12. Variations in RGP in response to vibration changes.

3.3.3. EWI Value According to Vibration Changes

When simple regression analysis was conducted to examine whether the EWI value exhibited a significant difference depending on vibration in the working state, the EWI values measured from the prefrontal lobe (Fp1 and Fp2) and right frontal lobe (F4) indicated a significant difference (* $p < 0.05$) depending on vibration (Table 12). The regression coefficients of EWI measured at the Fp1, Fp2, and F4 positions indicated positive correlations with values of 1.474, 1.424, and 0.54, respectively, indicating that the EWI value increased as vibration increased. The EWI values derived from other electrodes revealed no significant difference (* $p < 0.05$) depending on the vibration change.

Table 12. Result of simple regression analysis based on EWI in response to vibration changes ($p < 0.05$).

Dependent Variable		Independent Variable	*B*	*S.E.*	β	t	*p*	R^2
Prefrontal lobe	Fp1	constant	0.033	0.234	-	0.141	0.889	0.424
		Vibration (a_{rms})	1.474	0.245	0.651	6.004	0.000	
	Fp2	constant	0.052	0.228	-	0.229	0.820	0.420
		Vibration (a_{rms})	1.424	0.239	0.648	5.962	0.000	
Frontal lobe	F4	constant	0.667	0.216	-	3.094	0.003	0.104
		Vibration (a_{rms})	0.540	0.226	0.323	2.389	0.021	

Figure 13 compares RTP, RAP, RBP, and RGP among the three groups classified based on the RMS of vibration (0.315–0.630 m/s^2, 0.630–0.900 m/s^2, and 0.900–1.600 m/s^2). RGP at the prefrontal lobe (Fp1 and Fp2) and right frontal lobe (F4) gradually increased as the intensity of vibration increased. For the prefrontal lobe (Fp1 and Fp2), RBP was highest in the group that corresponds to 0.900–1.600 m/s^2, but it tended to be slightly lower in the group corresponding to 0.630–0.900 m/s^2 compared to the group corresponding to 0.315–0.630 m/s^2.

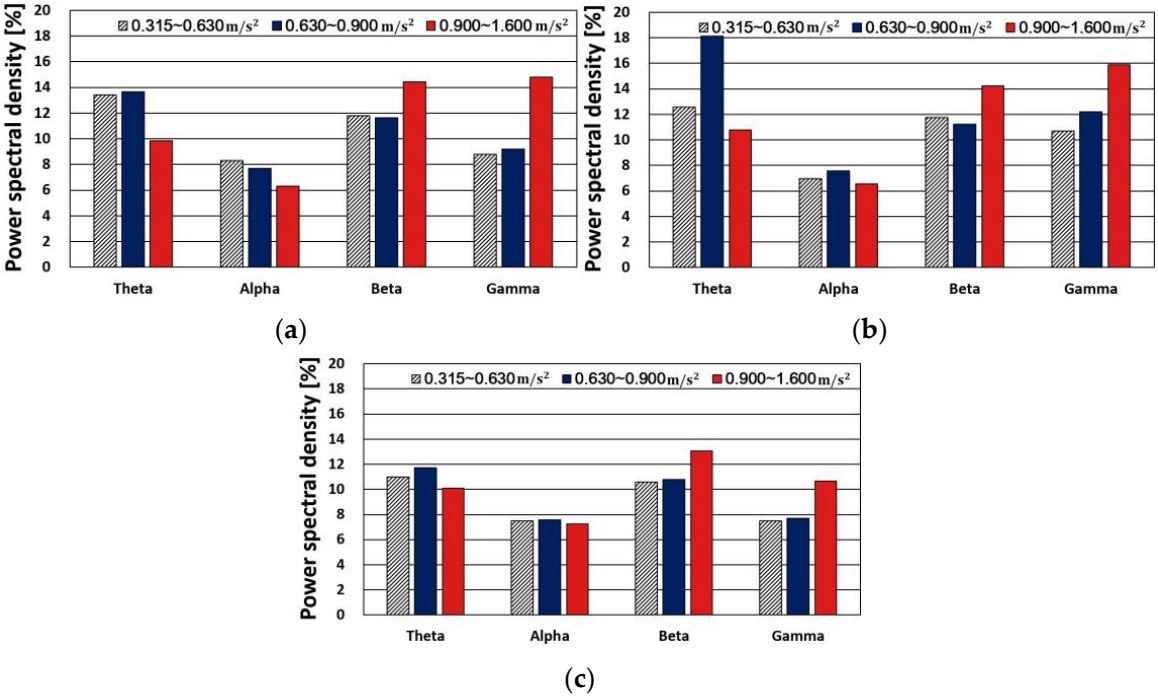

Figure 13. RTP, RAP, RBP, and RGP values in response to vibration changes: (**a**) Fp1 electrode; (**b**) Fp2 electrode; (**c**) F4 electrode.

As the sum of RBP and RGP was smaller than the sum of RTP and RAP or indicated no significant difference (* $p < 0.05$) depending on the state for the prefrontal lobe (Fp1 and Fp2) and right frontal lobe (F4), it is deemed inappropriate to evaluate the agricultural work stress caused by vibration with the EWI indicator. Figure 14 presents variations in EWI at the prefrontal lobe (Fp1 and Fp2) and frontal lobe (F4) for the three groups classified based on the RMS of vibration (0.315–0.630 m/s^2, 0.630–0.900 m/s^2, and 0.900–1.600 m/s^2).

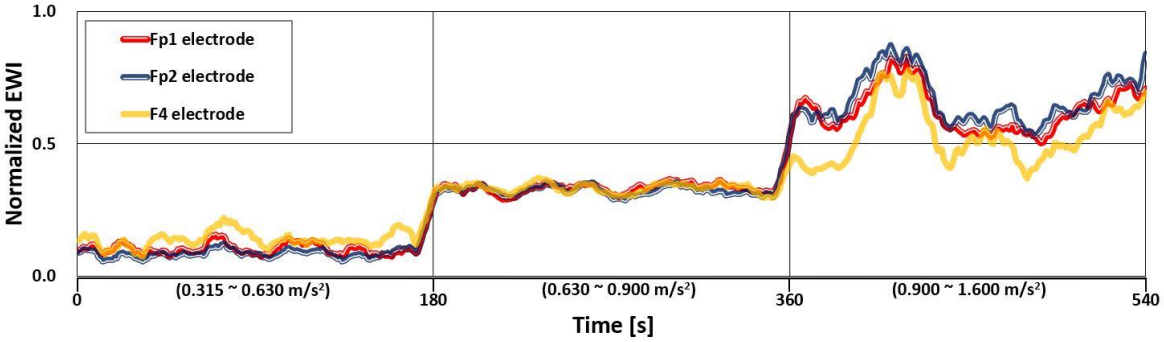

Figure 14. Variations in EWI in response to vibration changes.

4. Conclusions

In this study, EEG was measured for test participants who performed agricultural work with various agricultural machines. Agricultural work stress was analyzed in response to changes in the noise and vibration generated from agricultural machinery.

When agricultural work stress was examined, it was found that the stress occurred in the working state after rest (SEF95%: Fp2 and F8; RGP: Fp2 and F8; EWI: P3, P4, Pz, T5, T6, O1, and O2). As a result of statistical analysis, in a working state, the cerebral areas where the stress indicators increased alongside noise and vibration were found to be Fp2 of the prefrontal lobe based on SEF95% and RGP. In noise analysis, the regression coefficients of SEF95% and RGP measured at the Fp2 positions exhibited positive correlations with values of 0.539 and 0.006, respectively. In addition, the regression coefficients of SEF95% and RGP measured at the Fp2 positions in vibration analysis exhibited the values of 7.409 and 0.101, respectively. These results represent that SEF95% and RGP values increased as noise and vibration increased. This cerebral area was located in the right hemisphere. This appears to be because the right hemisphere of the brain tended to be activated when the participants handled negative emotions [63].

Yoon, Kim, and Chae [62] mentioned that various brain areas, including the prefrontal cortex, forebrain, hypothalamus, septohippocampal system, and amygdala, are involved when test participants are exposed to stress. The frontal lobe analyzes various data from the outside to make decisions and plays a major role in handling emotions [37,63–65]. Test participants who perform agricultural work with agricultural machinery are exposed to high noise and vibration levels [3]. It was also determined that agricultural work stress occurred while the participants acquired and responded to external information to operate agricultural machinery.

This study's results are expected to be utilized as foundational data to determine the agricultural work stress felt by farmers during work through EEG analysis or to analyze changes in agricultural work stress in response to changes in noise (61.42–88.39 dBA) and vibration (0.332–1.598 m/s^2). In addition, if SEF95% and RGP are utilized as indicators to analyze agricultural work stress, the prefrontal lobe (Fp2) can be utilized as an effective measurement position. This study was conducted under the assumption that factors other than vibration and noise do not affect brain stress. Therefore, a follow-up study will analyze various stress factors, including temperature, humidity, noise, and vibration, for various test participants (e.g., gender, age, height, and weight). Then, we plan to develop a multi-regression model that can predict stress according to changes in the level of stress factors in future research.

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