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An investigation of the influences of noise on EEG power bands and visual cognitive responses for human-oriented product design †

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Abstract

Various different human-oriented approaches are required in industrial activities. Noise is one of the most widespread sources of environmental stress. So, it is important to consider noise when we design human-oriented products. This study investigates the responses of EEG and eye movement data in order to evaluate the direct effects of low, middle, and high frequency noise on the two main physiological stress aspects: the EEG band power (alpha and beta frequency bands) and pupil response time (PRT) for a human-oriented product design. Fifteen subjects were exposed to low (100 Hz), middle (1000 Hz), and high frequency (10000 Hz) noise while awake. EEG and eye movement data were collected during noise exposure. Alpha band activity in low and high frequency noise ranges was smaller than that in no sound. Alpha band activity decreased 19.3 ± 4.5 % in the low frequency noise range. Additionally, alpha band decreased 19.5 ± 5.4% in high frequency noise range. On the other hand, Beta band activity in low and high frequency noise ranges was greater than that in no sound. Beta band activity increased 26.9 ± 7.9 % in the low frequency noise range and increased 30.6 ± 6.1% in high frequency noise range. The PRT, or visual cognitive responses, in low or high frequency noise was greater than that in no sound. PRT increased 15.3 ± 3.0% in low frequency noise range. Alternatively, PRT increased 18.1 ± 3.2% in high frequency noise range. And results of EEG and eye movement were statistically significant in low and high frequency noise ($r > 0.92$, $p < 0.05$). The findings of this study indicate that the stress induced by low frequency noise is as stressful as the stress induced by high frequency noise. Additionally, utilizing eye movement data and acquiring the PRT is useful in the analysis of human stress responses during various stressful situations in addition to the analysis of human stress responses during noise exposure.

Keywords: Electroencephalogram; Human-oriented product design; Noise; Pupil response time; Visual cognitive responses

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1. Introduction

Noise is an increasing problem in our environment nowadays, especially the kind of ‘‘unwanted sounds’’ that influence health negatively [1]. The experiences of noise stress are common to all living things. Noise is a pervasive aspect of living and work environments, thanks to urbanization and industrialization, for examples, factory, traffic, car, air-conditioner noise, etc. [2-5]. Particularly, low frequency noise, the frequency of which ranges below 100 Hz, is generated by many machines commonly used in the working environment, such as fans, blowers, compressors, and so on [6].

Emotions can be expressed via several channels and various features can be analyzed to assess the emotional state of a participant. Most studies focus on the analysis of facial expressions or of speech [7, 8]. But, these types of signals can however (more or less) easily be faked. Physiological signals can be divided into two categories: those originating from the peripheral nervous system (e.g. heart rate, Electromyogram, galvanic skin resistance), and those coming from the central nervous system (e.g. Electroencephalograms). In recent years interesting results have been obtained with the first category of signals [9, 10]. Very few studies however have used the second category [11], even though the cognitive theory states that the brain is heavily involved in emotions [12]. Basic emotions utilize specific cortical and subcortical brain systems, and have been differentiated by regional brain electrical activity and cerebral metabolism activity [13]. Various forms of psychology are associated with abnormal patterns of EEG activity in a particular band or bands.

The EEG is usually described in terms of its frequency components, which range over two orders of magnitude, from 1 to 100 Hz (oscillation periods from 10 to 1000 ms). By convention this range is subdivided into delta (1- 4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-25 Hz), gamma (35 Hz upwards), bands [14]. EEG varies greatly between individuals

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[15], is stable within an individual in a given condition (e.g. at rest with eyes closed) [16], changes according to mental state [17], and age [18], etc. In the study, delta, theta and gamma activities are rare or non-existent. The focus of this article is therefore the oscillations in the alpha and beta.

An underlying assumption in emotion EEG research is that in creased 8-13 Hz alpha activity is associated with decreased cortical activity in that cortical region [19], and that the relative contribution of the two hemispheres, and regions within the hemispheres, to different emotional states can be inferred by evaluating the relative power of alpha activity [9]. Higher frequency EEG activity appears in many cortical areas and may be indicative of different types of emotional, cognitive and attentional processes. Certain beta frequency oscillations found within specific beta frequency bands are thought to reflect states of neuronal networking of specific cortical and subcortical cell assemblies during which cognitive and sensory inputs are being processed and acted upon [20]. Beta activity, particularly in the temporal region, has been implicated in emotional processing.

Fig. 1. A picture of experiment.

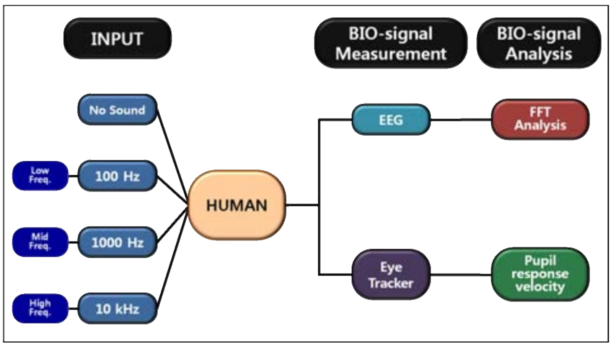


Fig. 2. Method of experiment.

Two types of voluntary eye movements are attributed to primates: one is a movement, known as saccade, in which the retinal images of the objects of interest are placed onto the fovea; and the second is a movement that maintains those images there, an activity known as pursuit. Saccades are discrete ballistic movements that direct the eyes quickly toward a visual target, thereby translating the image of the target from an eccentric retinal location to the fovea within tens of milliseconds. Pursuit is a continuous movement that rotates the eyes smoothly and slowly to compensate for any motion of the visual target and thus minimizes the drift of the target's image across the retina that might otherwise blur the image and compromise visual acuity [21]. In a visual search task, one tries to find a target object from among a group of distractor objects. Search can vary in speed depending on how much the target differs from the distractors [22]. The visual search task and PRT can be used as a tool to predict the negative effect during noise exposure, in which noise is used as one of distractors. The PRT is the same meaning of the response time of eye movement for visual search task.

This study investigates EEG and eye movement data in order to evaluate direct effects of low, middle, and high frequency noise on two main physiological stress responses: the EEG band power (alpha and beta frequency bands) and the PRT for human-oriented product design.

2. Method

2.1 Experimental procedure

A total of fifteen students from Sungkyunkwan University were voluntarily participated in this study. All of them were male aged between 25 to 30 years old with the same educational level background. They reported no history of hearing impairment and showed no signs of psychiatric or neurological disorders. The subjects were tested in a soundproof chamber. For auditory stimulation, speakers were equally spaced. Each subject remained seated in a chair during the experiment (Fig. 1). Each subject was exposed to low (100 Hz), middle (1,000 Hz), and high frequency (10,000 Hz) noise while awake (Fig. 2). The time span of the experiment comprised of a relaxation phase in which 10 minutes lacked acoustic content. The relaxation phase was followed by 5 minutes noise exposure. EEG and eye movement data were collected during noise exposure (Fig. 3).

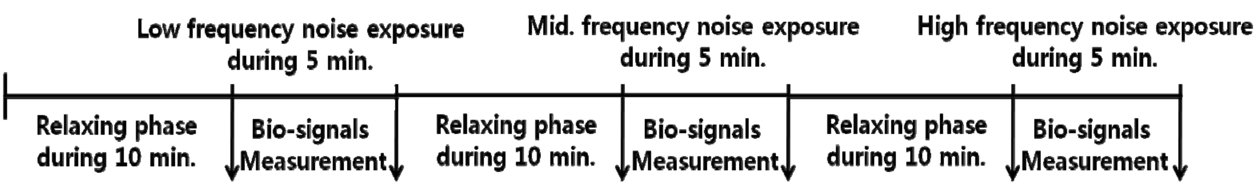
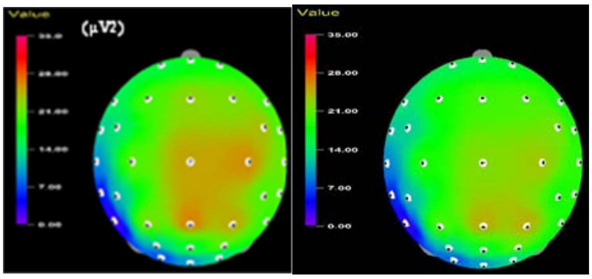
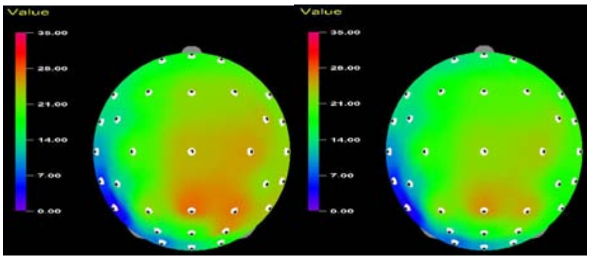


Fig. 3. Experiment procedure.

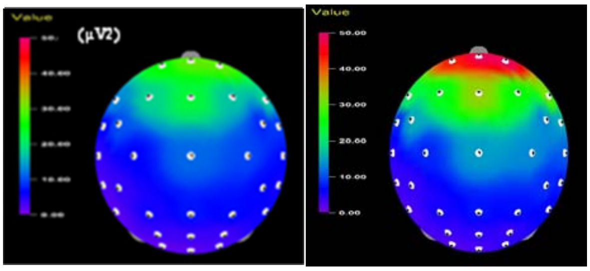


(a) No sound (b) 100 Hz

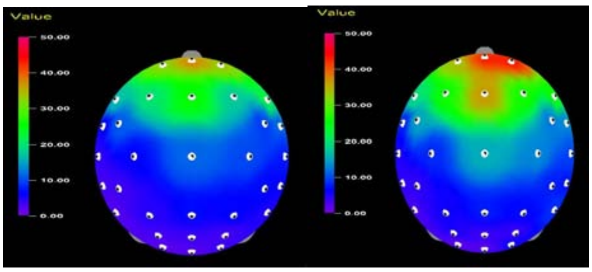


(c) 1000 Hz (d) 10000 Hz

Fig. 4. An example of alpha (8–13 Hz) frequency bands 3-D mappings.



(a) No sound (b) 100 Hz



(c) 1000 Hz (d) 10000 Hz

Fig. 5. An example of beta (13-25 Hz) frequency bands 3-D mappings.

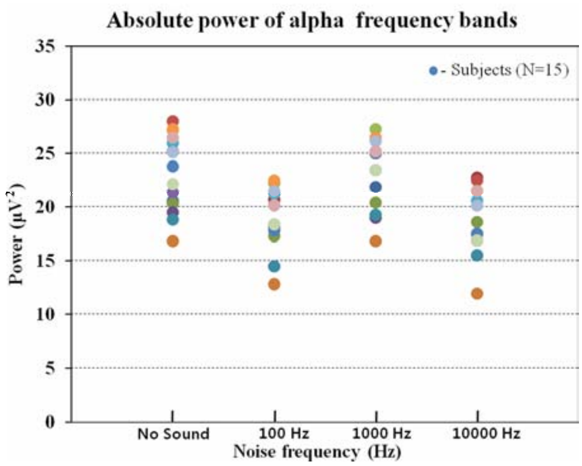


Fig. 6. Absolute power of alpha (8-13 Hz) frequency bands.

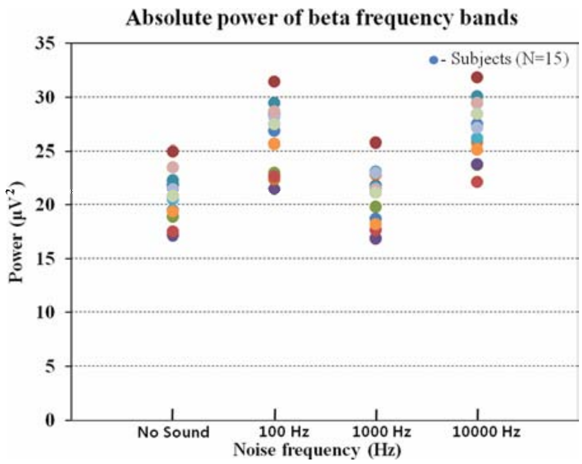
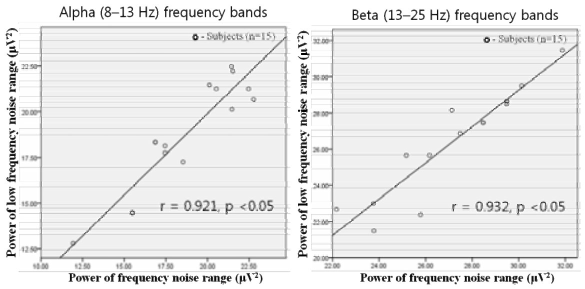


Fig. 7. Absolute power of beta (13-25 Hz) frequency bands.

2.2 EEG recording and analysis

The methods of EEG-recording and spectral analysis have been similar in the investigations that are presently described. EEG was recorded with digital equipment (model LXC3203; LAXTHA Inc.) with 32 surface electrodes and locations according to the international 10−20 system over frontal (Fpz, Fp1, Fp2, Fz, F3, F4, F7, F8, Fc5, Fc6, Fc7, and Fc8), temporal (T7, T8, Tp7, and Tp8), central (Cz, C3, C4, Cp5, and Cp6), parietal (Pz, P3, P4, P7, P8, Poz, Po3, and Po4) and occipital (Oz, O1, and O2) areas. Linked mastoids (A1+A2) were used as reference in the calculation of the power parameters. The impedance was kept along the experiment below 50 kΩ. The EEG signal was sampled at 256 Hz, with cut off frequencies below 0.5 and above 50 Hz. Subjects were asked to minimize blinking, head movement, and swallowing during the experiment. Bad channels were identified by visual inspection, and their voltage values were set to zero. Trials with EEG activity greater than 100 µV were automatically eliminated. The remaining trials were visually inspected, and those with blinks and movement artifacts were eliminated. After the subjects sat quietly for 10 minutes, 5 minutes of data were collected during noise exposure using stress analysis software. Data were stored in a computer for subsequent review, artifact rejection, and calculation. A customized program was used to perform the review and calculation of data. Power spectra were calculated with fast Fourier transformation (FFT) with a 4 s time window, from which an average spectrum of each channel was obtained in each subject. The EEG signals obtained were pre-processing using Band-pass filter to classify alpha and beta waves. Then the filtered signals were converted into power spectral density representation by using the



(a) (b)

Fig. 8. Regression curve of alpha and beta band activity.

LAXTHA software in order to measure the magnitude of each alpha and beta wave. The power spectral density for alpha and beta wave was obtained by computing the average of power spectral density for alpha frequency that range between 8-13 Hz and calculating the average of power spectral density for beta frequency that range between 13-25 Hz.

2.3 Eye movement recording and analysis

Eye positions were monitored with a 2-D Eye Tracker (Chronos Vision GmbH, Berlin, Germany) that measures horizontal and vertical eye positions at a sampling rate of 200 per second with 2 ms latency. The system consists of a remote camera assembly that traces the outline of the pupil by means of digital image processing (online 2-D, 11 bit output range) of the eyes that are illuminated by infrared LEDs (940 nm). The camera assembly is provided with a customized lens adapter; lens selection is dependent on the geometry and illumination conditions of the application and measures the two-dimensional pupil position in real time. The measurement range, both horizontal and vertical, is between −40° and +40°, with resolution of <0.05°. The Chronos Vision Eye Tracker has a measurement error of <0.2°. Before each measurement a calibration was made. In this experiment, the subject repeatedly focused on a fixed spot located at the center of the screen. Then four reference points were located at a distance of 10° (right/left/up/down) while the eye tracker calculated the data to provide an objective coordinate system.

Black shapes presented on a blank computer screen (24 inches wide) were used as visual stimuli. Each subject was positioned 100 cm in front the screen, with the head immobilized by a chin rest. Each trial began with a subject fixation that appeared on the eight points of the compass of the screen. An experiment proctor stood in front of the subject to ensure that fixation was correctly maintained by the test subject; and if so, the proctor initiated the continuation of the trial. Eye movements were recorded during sessions lasting up to 1 minute while noise exposure. The average location of the eye positions were collected throughout the session.

2.4 Statistical analysis

The statistical analysis was performed using SPSS statistical package version 18. 0. 0 for Windows. A correlation analysis

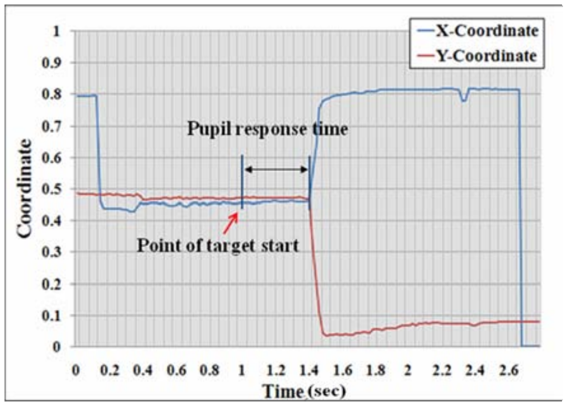


Fig. 9. Eye movements and pupil response time.

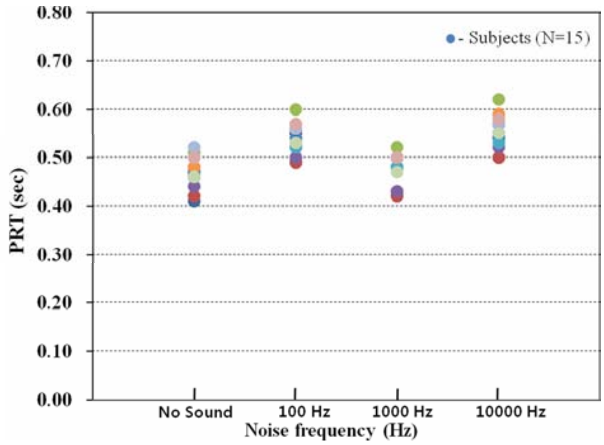


Fig. 10. Pupil response time.

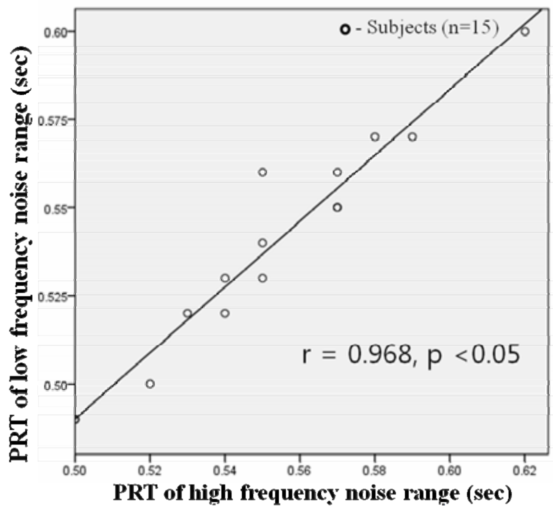


Fig. 11. Regression curve of pupil response time.

was performed to analyze whether there is a statistically significant differences in low and high frequency noise range during noise exposure. A probability level of $p < 0.05$ was taken as significant.

3. Result

3.1 EEG

In order to further evaluate the applicability of EEG data, power spectrum estimates were used to quantify alpha (8-13 Hz) and beta (13-25 Hz) frequency bands. An example of alpha band activity is shown in Fig. 4. Alpha band activity in low and high frequency noise ranges was smaller than that in no sound. Alpha band activity decreased 19.3 ± 4.5 % in the low frequency noise range. Additionally, alpha band decreased 19.5 ± 5.4% in high frequency noise range (Fig. 6). The data of low and high frequencies showed correlation coefficients of 0.921 and $p < 0.05$ (Fig. 8a).

An example of beta band activity is presented in Fig. 5. Beta band activity in low and high frequency noise ranges was greater than that in no sound. Beta band activity increased 26.9 ± 7.9 % in the low frequency noise range and increased 30.6 ± 6.1% in high frequency noise range (Fig. 7). The data of low and high frequencies showed correlation coefficients of 0.932 and $p < 0.05$ (Fig. 8b). This result shows that the stress induced by low frequency noise is as stressful as that induced by high frequency noise.

3.2 Eye movement

We measured the time required by each test subject to search for the target point during noise exposure while simultaneously recording eye movement (Fig. 9). The PRT of each subject is presented in Fig. 10. PRT in low and high frequency noise ranges was greater than that in no sound. PRT increased 15.3 ± 3.0% in low frequency noise range. Alternatively, PRT increased 18.1 ± 3.2% in high frequency noise range. The data of low and high frequencies showed correlation coefficients of 0.968 and $p < 0.05$ (Fig. 11). The PRT measurements show that the stress induced by low frequency noise is as stressful as that induced by high frequency noise. Recall that these findings correlate with those of the EEG analysis.

4. Conclusions

The results of this study confirm that noise is a definite stressor. The study participants were exposed for 5 minutes to noise samples of low (100 Hz), middle (1000 Hz), and high frequency (10000 Hz) at the noise level of 70dB. These specific noise frequency levels were chosen to meet the standards of each, frequency band. Analyses were conducted to evaluate possible differences in physiological stresses of low, middle, and high frequency noise exposure. The findings of this study indicate that the stress induced by low frequency noise is as stressful as that induced by high frequency noise. Additionally, it can be assumed that stress induced by noise causes psychological dysfunction and negatively affects visual cognitive response. Thus, considering noise exposure plays an important role in determining design factors for human-oriented product. Furthermore, the method of observing PRT using eye movement technology is potentially useful in the analysis of human stress responses during various stressful situations in addition to noise exposure. Various different human-oriented approaches are also required in different industrial activities. Examples from manufacturing include the need for assessment of sensibility facts in product planning. So, it is important to consider noise which affects human's feeling when we design human-oriented products.

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