An investigation of the influences of pure-tone noise on multi-variable bio-signals for product design with human sensibility engineering

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This study investigated whether multi-variable bio signals could be used for product design with human sensibility engineering. Twenty human subjects were exposed to low (100 Hz), middle (1000 Hz), and high frequency (10000 Hz) noise of pure-tone while awake. Electrocardiogram (ECG), electroencephalogram (EEG), eye tracking data was collected during various frequencies of noise exposure. SNS activity in low and high frequency noise ranges was greater than that in no sound. SNS activity increased 10.86 ± 2.44 % in the low frequency noise range and increased 12.43 ± 2.35 % in high frequency noise range. On the other hand, PNS activity in low and high frequency noise ranges was smaller than that in no sound. PNS activity decreased 10.18 ± 2.14 % in the low frequency noise range. 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 latency saccadic eye movement (LSEM), or visual cognitive responses, in low or high frequency noise was greater than that in no sound. LSEM increased 15.3 ± 3.0% in low frequency noise range. Alternatively, LSEM increased 18.1 ± 3.2% in high frequency noise range. And results of ECG, 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, the method of observing LSEM using eye tracker technology is potentially useful in the analysis of human stress responses during various stressful situations in addition to noise exposure. Various different human sensibility engineering approaches are also required in different industrial activities. Examples from manufacturing include the need for assessment of sensibility facts in product planning. Through this study, we can translate the consumer's feeling toward a product into design elements of that product.

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1. Introduction

When a person wants to use products, he or she has a feeling of the product as being luxurious, comfortable, and so forth. Human sensibility is the term used to describe such psychological feelings that humans attach to products. Therefore, various different human sensibility approaches are required in industrial activities.

Today, the experiences of stress are common to all living things. And noise is one of the most widespread sources of environmental stress. The effects of noise on human health, the auditory systems, and the development of deafness have been extensively studied since the 19th century [1, 2]. It has been found that noisy environments can cause psychological, physiological, and behavioral stress in people, as well as affect sleep, work efficiency and performance, and communication abilities [3]. The effects of noise vary depending on the characteristics of noise, such as intensity and frequency [4], exposure time and form, individual age, sex, and health condition. So, it is important to consider noise when we design products.

ECG is a diagnostic tool that measures and records the electrical activity of the heart in exquisite detail. Interpretation of these details

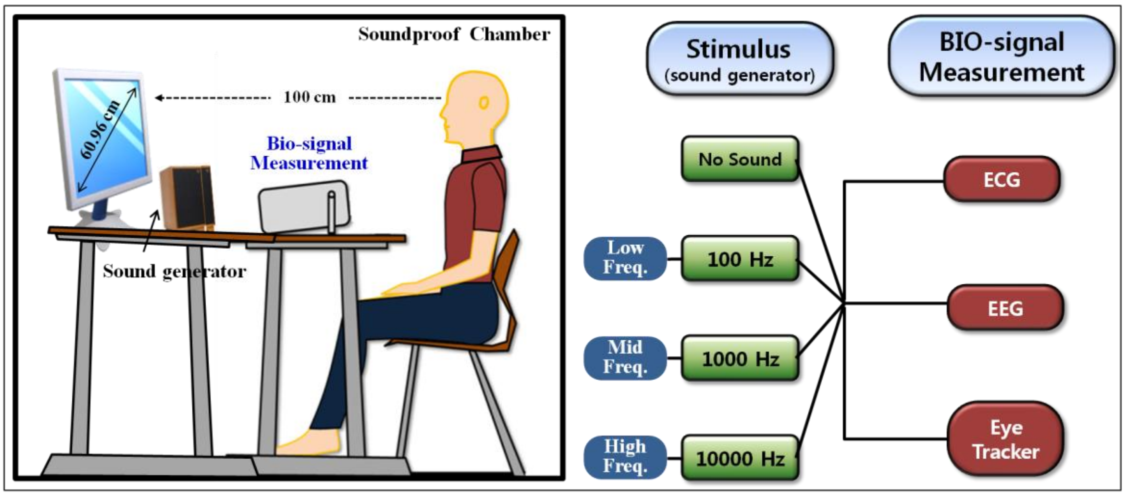


Fig. 1 Experiment schematic.

allows diagnosis of a wide range of heart conditions. ECG is a reflection of the many physiological or psychological factors modulating the normal rhythm of the heart which represents the variations in the beat-to-beat alteration in the heart rate. Particularly, the analysis of heart rate variability is important when studying the autonomic nervous system because it helps in evaluating the equilibrium between the sympathetic and parasympathetic influences on the heart rhythm. The sympathetic branch of the nervous system increases the heart rhythm, resulting in shorter beat-to-beat intervals, and the parasympathetic branch decelerates the heart rhythm, resulting in longer beat-to-beat intervals [5]. Also ECG can be a very useful tool not only for the diagnosis of adverse cardiac events, but also for predicting the risk of negative effects during noise exposure.

Basic emotions utilize specific cortical and subcortical brain systems, and have been differentiated by regional brain electrical activity and cerebral metabolism activity [6]. Various forms of psychology are associated with abnormal patterns of EEG activity in a particular band or bands.

The present experiment utilized EEG spectral analysis to investigate lateralization for emotional processes in the human brain. In frontal zones, a differential lateralization for positive and negative emotion was observed, with relative left-hemispheric activation (as measured by decreases in alpha abundance) for positive emotions and relative right-hemispheric activation for negative emotions. In parietal zones, a differential lateralization for verbal and spatial processes was observed, with relative left-hemispheric activation for verbal questions and relative right-hemispheric activation for spatial questions. Examination of EEG bands other than alpha (i.e. delta, theta, beta, and total power) suggested that emotional and cognitive processes are further distinguished by different EEG spectral patterns. Alpha EEG activity, a sinusoidal rhythm with a frequency of 8–12 Hz, is the predominant EEG frequency recorded during passive wakefulness. It is recorded most prominently over the occipital and parietal regions of the scalp and is attenuated by eye opening and noise. Ray and Cole found temporal beta (16-24 Hz) activity to be more abundant in negative than positive emotion, possibly because of a deeper involvement in the negative emotion [7].

In a visual search task, atypical stimulus for lateral saccadic eye movement is the sudden lateral displacement of a small, bright spot in a dark field. The eyes of a normal human subject who has been instructed to watch such a spot will be so directed as to place the central foveal regions of the eyes under the image of the spot. When a sudden spot displacement occurs, a saccadic eye movement to the new position will occur in about 200 msec [8]. Also 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 [9, 10]. The visual search task (latency of saccadic eye movement) will be used as a tool to predict the negative effect during noise exposure, in which noise is used as one of distractors.

This study investigates ECG, EEG and eye tracker data in order to evaluate direct effects of low, middle, and high frequency noise on three main physiological stress responses: the autonomic nervous system, the EEG band power (alpha and beta frequency bands) and the latency of saccadic eye movement.

2. Method

2.1 Experimental design

The experiment involved twenty male subjects aged 25–30 years free of cardiovascular disease and with normal functional hearing. 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. Each subject was exposed to low (100 Hz), middle (1000 Hz), and high frequency (10000 Hz) containing noise levels from 70dB while awake (Fig. 1). The time

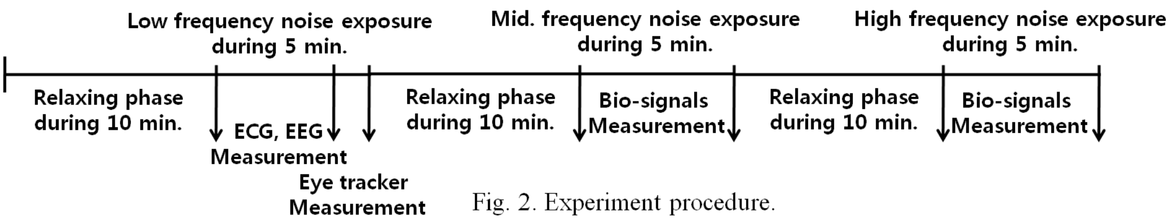
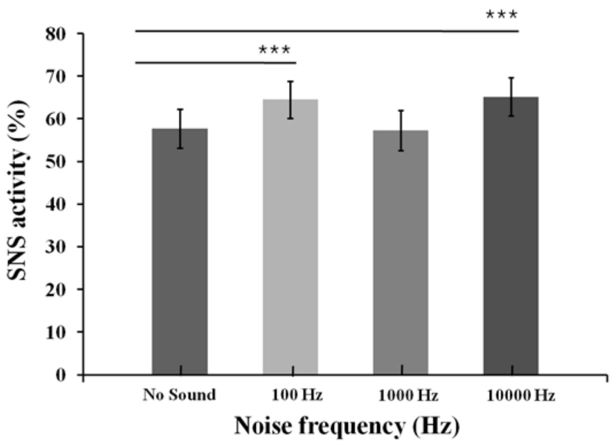
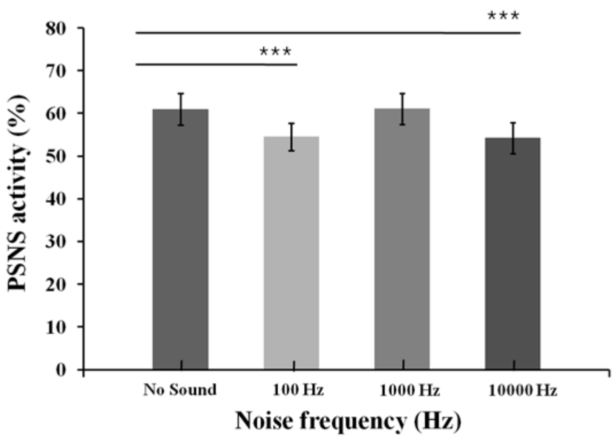


Fig. 2. Experiment procedure.



(a) Sympathetic nervous system activity



(b) Parasympathetic nervous system activity

Fig. 3 Sympathetic and parasympathetic nervous system Activity

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. ECG, EEG and eye tracker data were collected during noise exposure (Fig. 2).

2.2 ECG

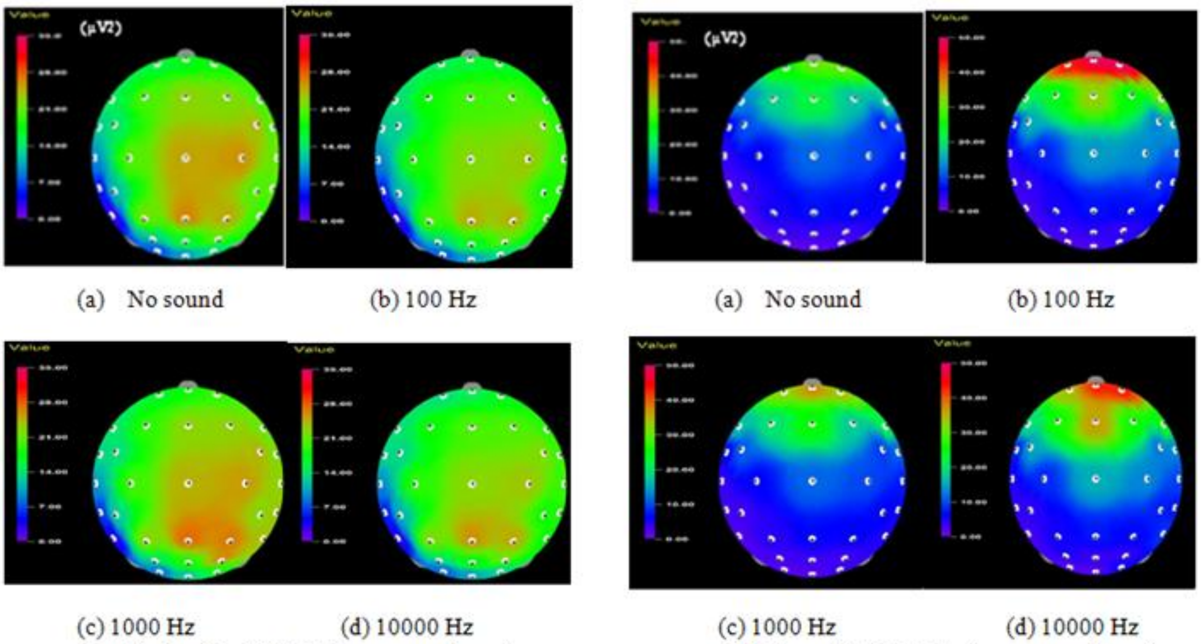
Subjects were equipped with an ECG (model LXC3203; LAXTHA Inc. Korea) that relayed ECG data to an analogue-to-digital converter. In all cases, the sampling frequency was 256 Hz. The patient's skin was shaved and rubbed with sandpaper at the location of the electrode. The electrodes were 4-pole Sensor T-CC-C-EL-00 (LAXTHA Inc. Korea). 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 (Fig. 3). Then the ECG signals were converted into heart rate variability by using the LAXTHA stresses analysis software in order to calculate the SNS and PNS activity. 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. Spectral power analyses were performed in accordance with previously published standards yielding two frequency domain measures of low frequency (LF) power (0.04–0.15 Hz) and high frequency (HF) power (>0.15 Hz) of heart rate variability.

2.3 EEG

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

Table 1. One-way Analysis of Variance (ANOVA) of ECG

Comparison	Sympathetic nerve system activity			Parasympathetic nerve system activity		
	Mean Difference	q	P value	Mean Difference	q	P value
No Sound vs 100Hz	-6.792	6.717	*** P<0.001	6.458	8.137	*** P<0.001
No Sound vs 1000Hz	0.4110	0.4065	ns P>0.05	-0.1175	0.1481	ns P>0.05
No Sound vs 10000Hz	-7.462	7.380	*** P<0.001	6.748	8.503	*** P<0.001
100Hz vs 1000Hz	7.203	7.123	*** P<0.001	-6.575	8.286	*** P<0.001
100Hz vs 10000Hz	-0.6700	0.6627	ns P>0.05	0.2900	0.3654	ns P>0.05
1000Hz vs 10000Hz	-7.872	7.786	*** P<0.001	6.865	8.651	*** P<0.001



(a) Alpha (8–13 Hz) frequency bands (b) Beta (13–25 Hz) frequency bands

Fig. 4 An example of alpha and beta frequency bands 3-D mappings.

calculated with fast Fourier transformation (FFT) with a 2.5 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 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.

2.4 Eye tracker

Eye positions were monitored with 2D Eye Tracker (Chronos Vision GmbH, Berlin, Germany) that measures horizontal and vertical eye positions at a sampling rate of 200 per second with a 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 2D, 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 $+40^\circ$, with resolution of $<0.05^\circ$. The Chronos Vision Eye Tracker has a measurement error of $<0.2^\circ$. 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.

Subjects were seated 100 cm in front of a computer screen (24 inches wide) on which a small target was displayed against a black background in an otherwise dark room. The subject's head was stabilized 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 patient 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. This average was taken as the assumed true fixation.

2.5 Statistical Analysis

The statistical analysis was performed using SPSS statistical Package version 18. 0. 0 for Windows. The data were expressed as mean S.E. A correlation analysis was performed to analyze whether there is a statistically significant differences in low and high frequency noise range during noise exposure. The differences between each group were compared by One-way ANOVA. $p < 0.05$ was considered statistically significant.

3. RESULTS

2.1 ECG

In order to further evaluate the applicability of ECG data, power spectrum estimates were used to quantify SNS activity and PNS activity. SNS activity is presented in Fig. 3a. SNS activity in low and high frequency noise ranges was greater than that in no sound. SNS activity increased 10.86 ± 2.44 % in the low frequency noise range and increased 12.43 ± 2.35 % in high frequency noise range. The data of low and high frequencies showed correlation coefficients of 0.936 and $p < 0.05$ (Table 1).

PNS activity is shown in Fig. 3b. PNS activity in low and high frequency noise ranges was smaller than that in no sound. PNS activity decreased 10.18 ± 2.14 % in the low frequency noise range. Additionally, PNS activity decreased 11.34 ± 2.07 % in high frequency noise range. The data of low and high frequencies showed correlation coefficients of 0.993 and $p < 0.05$ (Table 1). This result shows that the stress induced by low frequency noise is as stressful as that induced by high frequency noise.

2.2 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. 4a. 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. The data of low and high frequencies showed correlation coefficients of 0.921 and $p < 0.05$. An example of beta band activity is presented in Fig. 4b. 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 data of low and high frequencies showed correlation coefficients of 0.932 and $p < 0.05$. This result shows that the stress induced by low frequency noise is as stressful as that induced by high frequency noise.

2.2 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. LSEM in low and high frequency noise ranges was greater than that in no sound. LSEM increased 31.60 ± 7.75 % in low frequency noise range. Alternatively, LSEM increased 36.05 ± 7.75% in high frequency noise range. The data of low and high frequencies showed correlation coefficients of 0.966 and $p < 0.05$. The LSEM 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 ECG and EEG analysis.

4. Conclusions

The results of this study confirm that noise is a definite stressor using multi-variable bio signals. Many studies have examined the influence of noise on human physiology and psychology. However, few studies have examined of the influences of noise on multi-variable bio signals. The specific noise frequency levels which were used for the experiment 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 sensibility product. Furthermore, the method of observing LSEM using eye tracker technology is potentially useful in the analysis of human stress responses during various stressful situations in addition to noise exposure.

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