Safety Management and Human Factors, Vol. 64, 2022, 135–143
https://doi.org/10.54941/ahfe1002638

Analysis of Pre-Evacuation Time and EEG for Fire Alarm When Wearing ANC Earphones

Ji-Won Gu, Ji-Hoon Hwang, Ryun-Seok Oh, and Jun-Ho Choi

Division of Architecture and Fire Protection Eng., Pukyong National University, Busan 48513, South Korea

ABSTRACT

Active noise control (ANC) earphones block even the alarm sounds designed to inform people of incoming danger, thereby placing people at risk. This study measured the recognition degree of fire alarm sounds based on 20 male and female subjects in their 20s, who wore ANC earphones and responded to the fire bell alarm (FBA), and the alarm sound from the emergency public address system (EPAS), both representative alarm sounds. In this study, electroencephalograms (EEGs) of the participants were measured to analyze their psychological responses. Based on results, the pre-evacuation time was calculated, which was used to identify the degree of evacuation delay. The calculation results showed that subjects using the ANC function evacuated more quickly by 13.5 seconds when they heard the EPAS alarm sound than when they heard the FBA. Moreover, the arousal responses of subjects, such as nervousness, irritation, and restlessness, was also analyzed based on their EEGs. It was found that the EEG measurement results were insignificant in both cases, in which the FBA or EPAS alarm sounds were played with the ANC function turned on. In addition, subjects required a longer pre-evacuation time of 40–50s in response to the fire alarm created when they used the ANC function than when they did not use it in both cases.

Keywords: Active noise control/cancelling (ANC) earphones, Pre-evacuation time, Electroencephalogram (EEG), Fire alarm

INTRODUCTION AND OVERVIEW

Recently, there has been increasing interest in Bluetooth earphones equipped with an active noise control/cancelling (ANC) function, used to block external noise from earphones. However, ANC earphones have a problem in that they block not only the surrounding background noise, but also emergency alarm sounds designed to inform people about the occurrence of danger, such as honks and fire alarm sounds. The fire alarm sound serves as an important medium that accurately and swiftly motivates people to escape to a safe location, thus reducing the evacuation time (Proulx, 2007). In a study conducted by Proulx, occupants who underwent evacuation believed that an emergency situation was terminated and returned to their original places as soon as the fire alarm sound stopped. Based on this observation, Proulx emphasized the importance of fire alarm sounds (Proulx, 1995).

Table 1. Classification of types of experimental cases.

	Case I	Case II	Case III	Case IV
ANC function operation	ON	ON	OFF	OFF
Types of fire alarms	FBA	EPAS	FBA	EPAS

Research on restrictions on the maximum output volume of ANC Bluetooth earphones has been conducted to develop surrounding noise canceling technology and prevent hearing loss. However, few studies have analyzed the problem of emergency alarm sounds being removed when ANC earphones are worn (Hirave, 2011; Kuo, 2018; Struck, 2019). Only a small number of researchers have examined evacuation delays based on whether ANC earphones are worn in the field of human behavior in case of fire. In particular, the psychological and physiological responses of those who undergo an evacuation affect the total evacuation time during the response phase. Relevant data have been obtained primarily through interviews or surveys, but these data collection methods reflect the subjective opinions of participants and thus reduce data reliability (Christensen, 2008; Purser, 2008; Pan, 2007; Ren, 2008; Minh, 2010; Zhou, 2019). Thus, this study analyzed changes in subjects' EEG to quantitatively measure their emotional or sentimental changes and identify the effect of these changes on evacuation delays.

METHODOLOGY AND EXPERIMENTAL CONTEXT

Scenario

This study measured subjects' EEGs and the evacuation delay time they exhibited before they recognized the fire alarm sound and performed the evacuation. To this end, 20 subjects were selected and divided into two groups: earphone wearers with the ANC mode turned on and earphone wearers with the ANC mode turned off. Experiments were carried out in a lecture room at P University, where ANC earphones were frequently used and where fire situations could be practically implemented. The subjects were required to wear devices for EEG measurements. These experiments were conducted with the approval of the affiliated organization through an ethical review board (IRB NO: 1041386-202110-HR-56-01). In the experiments, subjects heard the fire bell alarm (FBA) and the alarm sound created from the emergency public address system (EPAS), which are generally used as fire alarm sounds. The fire alarm sounds used in the experiments were sound sources that complied with National Fire Safety Codes (NFSCs) 201 and 202, and the experiments were categorized into four cases (see Table 1).

Fire alarm sounds were played for 3 minutes according to ISO 8201, and the FBA was sounded at 90 dB based on a horizontal distance of 1 m. The EPAS sounded a 1 W siren at a horizontal distance of 25 m or shorter and delivered a message "Fire! Fire! Evacuate to the exit!" This study measured the EEGs of occupants when the FBA and EPAS broadcast sound were transmitted, as well as the pre-evacuation time required by using EEG measurement equipment and video cameras. Pre-evacuation time was defined as the

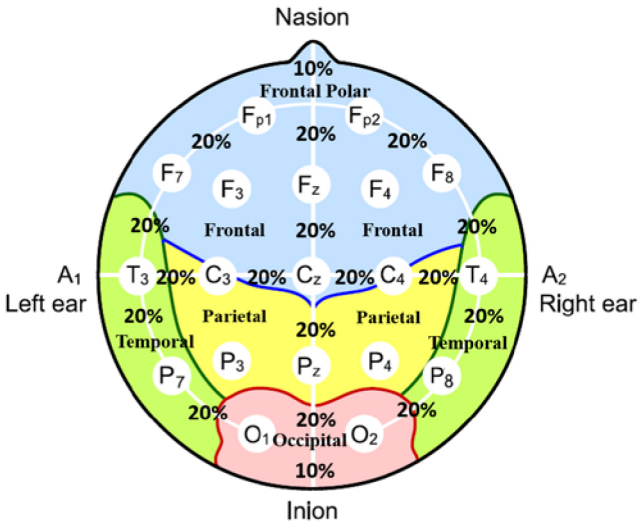

Figure 1: Locations of EEG measurement (Adapted from Bos, 2006)**.

amount of time that took a subject to stand up from his or her chair (Boyce, 2017; BSI, 2019).

Measuring Equipment

The Quick-8 wireless EEG system developed by Cognionics was used to measure EEG signals. The sampling rate was 500 Hz, based on 24 bits. The Bioteck Analysis system developed by Bioteck was used to investigate the EEG changes. Moreover, 20 channels, reference electrodes, and grounding electrodes were attached to the heads of the subjects according to an intentionally certified 10–20 electrode system (Khazi et al., 2012) (see Figure 1). This study measured the relative gamma power spectrum (RG), which indicates highly developed cognitive functions (e.g., tension, awareness, and stress), and the relative high beta power spectrum (RHB), which indicates a state of raised feelings (e.g., emotional anxiety, restlessness, excitement, and a feeling that a person shows when he or she performs a complex task), spectral edge frequency 50% (SEF50%), which is related to the degree of brain activation and attention, and spectral edge frequency 95% (SEF95%), which indicates the stress level. In the experiments, subjects wore AirPod Pro ANC earphones developed by Apple, which showed the highest purchase rate, and listened to the most popular songs on the chart when the research was conducted using these earphones. This study selectively turned on the noise-canceling mode, which enables a feed-forward (FF) microphone to detect external sound and attenuate it before it reaches the auditory organs, according to experimental cases (Case I, Case II).

Furthermore, the subjects were requested to avoid drinking alcohol, smoking cigarettes, and eating or drinking caffeine, all of which can affect EEGs, on the day prior to the day of the experiments. They were also asked to get enough sleep to avoid drowsiness.

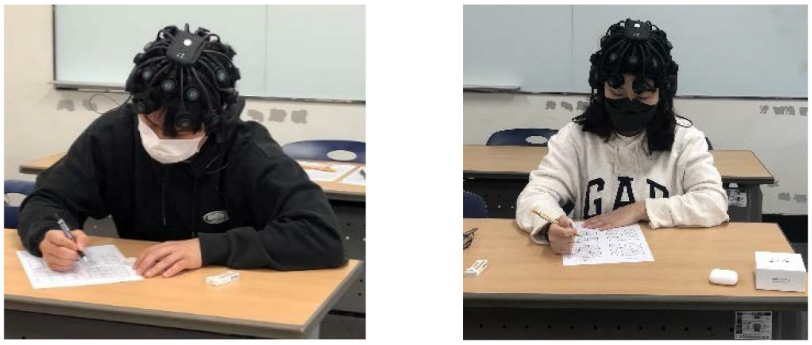

Figure 2: Examples of experiments conducted.

Procedure

Volunteers signed an agreement regarding participation in the experiments, entered the lecture room, and wore EEG measurement equipment in comfortable conditions. The subjects were asked to complete a survey while listening to music, which was irrelevant to the experiments of this study, to prevent them from predicting that fire alarm sounds would be delivered as part of the experiments. Moreover, all subjects were asked to leave the lecture room to prevent noise from disturbing them (see Figure 2).

Then, the fire alarm was sounded randomly and suddenly to measure changes in the EEG of subjects and document their behaviors based on video camera recordings. When the subjects opened the door and left the lecture room within 3 min of the occurrence of the fire alarm, this study regarded that they successfully escaped from the location, and the experiment was considered to have ended. When the subjects exhibited no response after 3 min following the occurrence of the fire alarm, the experiment was stopped. After the experiments were completed, participants were interviewed to investigate their motivation to evacuate.

DATA COLLECTION AND ANALYSIS PROCESS

Results of Measuring EEGs and Pre-Evacuation Time to Identify the Recognition Degree of Fire Alarm Sounds

An independent sample t-test based on RG, RHB, SEF50%, and SEF95%, which indicate EEGs on awakening, was carried out to statistically verify the difference in the recognition degree of the FBA and the fire alarm sounded from the EPAS according to the operation state of the ANC function on the subjects' earphones. As normality was not satisfied owing to an insufficient number of samples, the Mann–Whitney U-test was conducted (see Table 2). The data of two subjects, which were not converted owing to severe noise, were excluded from the analysis.

The result of calculating the pre-evacuation time was as follows: subjects in Case III ($n = 5$) and Case IV ($n = 4$), in which the ANC function was turned off, responded to the fire alarm more quickly by 43.8 secs and 53.5 secs, respectively, than those in Case I ($n = 4$) and Case II ($n = 5$), in

Table 2. ANC Mode ON/OFF vs. Recognition and Pre-evacuation Time (s).

ANC		Fire Bell Alarm			Emergency Public Address System		
ON	Recognition Time	Min.	Max.	Avg.	Min.	Max.	Avg.
		6	180	**128.5**	1	180	**84.3**
	Pre-evacuation Time	Min.	Max.	Avg.	Min.	Max.	Avg.
		13	180	**137.3**	8	180	**123.8**
OFF	Recognition Time	Min.	Max.	Avg.	Min.	Max.	Avg.
		1	105	**38.7**	1	14	**6.7**
	Pre-evacuation Time	Min.	Max.	Avg.	Min.	Max.	Avg.
		16	180	**93.5**	7	180	**70.3**

which the ANC function was turned on. Subjects in Cases III (n = 5) and IV (n = 4) tended to stop what they were doing to accurately listen to the fire alarm, stare in the direction from which the fire alarm was played, and concentrate on the sound (see Table 2). All the EEG data obtained from Case I were superior to those obtained from Case III. However, the superiority of the EEG data in Case I was statistically insignificant based on the following calculation results: RG $p>.486$, RHB $p>1.00$, SEF50% $p>.486$, and SEF95% $p>.686$. However, all EEG data obtained from Case IV were superior to those obtained from Case II. However, the superiority of the EEG data in Case IV was statistically insignificant based on the following calculation results: RG $p>.556$, RHB $p>.063$, SEF50% $p>.413$, and SEF95% $p>.556$ (see Table 3).

To identify the reasons for the aforementioned results, interviews with the subjects were analyzed. The analytic result indicated that subjects in Case I performed complex thinking processes to determine the situation because they could not listen to the fire alarm sound accurately as the ANC mode was turned on.

Consequently, their complex thinking processes increased their EEGs and pre-evacuation time delays (see Figure 3). In particular, comparatively high values were observed in the occipital lobe (O_1), which is the visual processing area, and parietal lobe (P_8 and P_7), which are responsible for physical movements and thinking processes, in Case I. These results indicate that the subjects in Case I showed frequent eye movements to analyze the surrounding conditions and performed thinking and recognition functions to understand the situation. In Cases III and IV, comparatively high values were observed at the occipital lobe (O_1) and the temporal lobe (T3), which is associated with sound recognition function. These results indicate that the state of the ANC mode being turned off supported the subjects in Cases III and IV to recognize and focus on the fire alarm more intensively and explore their surrounding conditions more actively. The aforementioned results verified that the occupants showed arousal responses owing to an increasing level of nervousness, anxiety, stress, and concentration as soon as they heard the fire alarm.

The results of the analysis of the recognition degree of the fire alarm sound according to the operation state of the ANC mode are as follows. In the environment with the ANC function turned on (Cases I and II), subjects showed

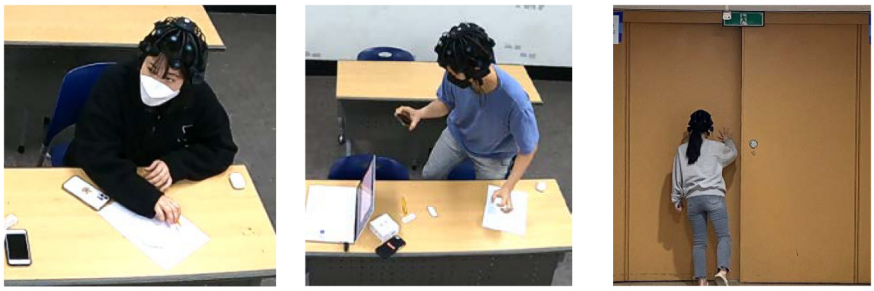

Figure 3: Examples of subjects' response and behaviors in relation to the fire alarm sound.

stronger arousal responses when they heard the FBA than when they heard the EPAS broadcast sound. However, these stronger arousal responses were determined to be statistically insignificant based on the following calculation results: RG $p>.413$, RHB $p>.286$, SEF50% $p>.286$, and SEF95% $p>.730$. In contrast, in the environment with the ANC function turned off (Cases III and IV), the subjects showed stronger arousal responses when they heard the EPAS broadcast sound than when they heard the fire alarm. However, the results of the significance test verified that such stronger arousal responses were statistically insignificant based on the following calculation results: RG $p>.190$, RHB $p>.143$, SEF50% $p>.190$, and SEF95% $p>.286$ (see Table 3). The results of analyzing the pre-evacuation time indicated that subjects in Case II evacuated more swiftly by 13.5 s than those in Case I and that subjects in Case IV evacuated more swiftly by 23.2 s than those in Case III. These results verified that the subjects showed more prompt responses when they heard the EPAS broadcast sound than when they heard the FBA, regardless of the state of the ANC function (see Figure 3). This study examined the mean values according to the channels to identify the reasons for such differences in the subjects' responses. The analytic results showed that the EPAS broadcast sound activated the subjects' parietal lobe (P_8), which is primarily used to transmit information to the muscle before a person performs a movement due to external stimuli (Leshinskaya, 2015). Consequently, the subjects prepared themselves for evacuation more actively when they heard the EPAS broadcast sound than when they heard the FBA. In addition, subjects showed a strong response at the occipital lobe (O_1) and rolled their eyes frequently when stimulated by the FBA. This study reviewed the interviews to identify the reasons for such strong responses and frequent eye-roll movements. The analytical results indicated that subjects recognized the FBA, which was played constantly, more easily than the EPAS broadcast sound, which was cut based on the unit of a syllable. However, they believed that FBA was caused by a malfunction or sounded as a test. Consequently, they frequently rolled their eyes to explore the surrounding areas.

Therefore, the result of analyzing the recognition degree of the fire alarm sound based on the EEG response in this study verified that the arousal response caused by the FBA did not differ from that caused by the EPAS broadcast sound. Thus, this study delivered a different result from an existing

Table 3. ANC mode ON/OFF vs. recognition and pre-evacuation time (s).

Division	Analytic Index	Case	Group Statistics				Mann–Whitney U Test	
			Avg		Channel value (Max)		Z	p
ANC ON vs OFF	**RG**	I vs III	0.282	0.214	0.389(O_1)	0.268(T_3)	−.866	.486
		II vs IV	0.237	0.285	0.311(O1)	0.384(O_1)	−.735	.556
	RHB	I vs III	0.153	0.134	0.199(O_1)	0.134(O_1)	.000	1.00
		II vs IV	0.133	0.164	0.166(P_8)	0.178(T_3)	−1.96	.063
	SEF50%	I vs III	16.711	12.797	24.395(O_1)	12.797(O_1)	−.866	.486
		II vs IV	13.633	17.151	18.870(P_8)	24.085(O_1)	−.980	.413
	SEF95%	I vs III	45.173	42.905	47.355(O_1)	45.276(P_7)	−.577	.686
		II vs IV	43.982	45.629	46.306(O_1)	47.183(O_1)	−.735	.556
FBA vsEPAS	**RG**	I vs II	0.282	0.237	0.389(O_1)	0.311(O_1)	−.980	.413
		III vs IV	0.214	0.285	0.268(T_3)	0.384(O_1)	−1.470	.190
	RHB	I vs II	0.153	0.133	0.199(O_1)	0.166(P_8)	−1.225	.286
		III vs IV	0.1334	0.164	0.134(O_1)	0.178(T_3)	−1.640	.143
	SEF50%	I vs II	16.711	13.633	24.395(O_1)	18.870(P_8)	−1.225	.286
		III vs IV	12.797	17.151	12.797(O_1)	24.085(O_1)	−1.470	.190
	SEF95%	I vs II	45.173	43.982	47.355(O_1)	46.306(O_1)	−.490	.730
		III vs IV	42.905	45.629	45.276(P_7)	47.183(O_1)	−1.225	.286

study (Gu, 2021), which reported the significance of the EPAS broadcast sound in the analysis of the degree of recognition of the fire alarm sound based on the EEG response.

CONCLUSION

This study analyzed the level of subjects' recognition of fire alarm sounds considering different types of fire alarm sounds and the operation state of the ANC function of earphones. The analytic results showed that subjects in Cases I and II, in which the ANC function was turned on, recognized the fire alarm sound later by 43.8 s and 53.5 s, respectively. However, these delays were not significant based on the RG, RFB, SEF50 %, and SEF95% results ($p>.05$). These results verified that subjects expressed arousal responses, such as anxiety, restlessness, and stress, when they heard the fire alarm, regardless of the application state of the ANC mode. Subjects in Cases II and IV, in which the EPAS broadcast sound was delivered, expressed more prompt responses by 13.5 s and 23.2 s, respectively, than subjects in Cases I and III, in which the FBA was delivered, regardless of the application state of the ANC mode. However, the analytical results of EEGs verified that these differences in response were not significant ($p>.05$). Accordingly, it was determined that the fire alarm activated the brain areas of subjects related to relevant cognitive processes and mental activity, regardless of the types of fire alarm sounds.

Moreover, in the video analysis, the subjects appeared to be stable until the recognition time. However, the analytic results of the EEG showed that they encountered negative feelings, such as anxiety, restlessness, and nervousness.

A limitation of this study is that the research results cannot be generalized because of the insufficient number of samples obtained.

ACKNOWLEDGMENT

This work was supported by a National Research Foundation of Korea grant (no. NRF-2018R1A2B3005951), which was funded by the Korean government and was also supported by the "National Fire Agency" R&D program (20016433).

REFERENCES

Boyce, K., McConnell, N. and Shields, J. (2017). "Evacuation response behaviour in unannounced evacuation of licensed premises". *Fire and Materials*, *41*(5), 454–466.

BSI Standards Publication, "Application of Fire Safety Engineering Principles to the Design of Buildings, Part 6: Human Factor: Life Safety Strategies - Occupant Evacuation, Behaviour and Condition (Sub-system 6)", PD 7974-6: 2019.

Christensen, K., and Sasaki, Y. (2008). "Agent-based emergency evacuation simulation with individuals with disabilities in the population", *Journal of Artificial Societies and Social Simulation*, *11*(3), 9.

Dong, W., Yu, C., and Zhibin, M. (2018). "Study of sound direction evacuation". In *Journal of Physics: Conference Series* 1107 (7), 072002. IOP Publishing.

Fire Safety Engineering Group, University of Greenwich (2022). Available form: http://fseg.gre.ac.uk/fire/besecu.html

Galea, E. R., Deere, S., Sharp, G., et al (2010). "Investigating the impact of culture on evacuation behaviour". In *Proceedings of the 12th International Fire Science & Engineering Conference, Interflam* 1, 879-892.

Gwynne, S., Galea, E. R., Parke, J., & Hickson, J. (2003). "The collection and analysis of pre-evacuation times derived from evacuation trials and their application to evacuation modelling", *Fire Technology*, *39*(2), 173–195.

Gu, J. -W. (2021)."Evaluation of Human Recognition and Affordance under the Fire Alarm and Emergency Alert Message through EEG Measurement", Master's Thesis, Pukyong National University

Hirave, P. P., and Pathak, B. (2011). "Fundamentals of active noise control for local cancellation of noise". In *2011 3rd International Conference on Electronics Computer Technology* 4, 246–249.

Khazi, M., Kumar, A., and Vidya, M. J. (2012). "Analysis of EEG using 10: 20 electrode system", *International Journal of Innovative Research in Science, Engineering and Technology*, *1*(2), 185–191.

Kuo, S. M., Chen, Y. R. and Chang, C. Y.,et al. (2018). "Development and evaluation of light-weight active noise cancellation earphones". *Applied Sciences*, *8*(7), 1178.

Leshinskaya, A., and Caramazza, A. (2015). "Abstract categories of functions in anterior parietal lobe". *Neuropsychologia*, *76*, 27–40.

Minh, L. V., Adam, C.,and Canal, R., eat al. (2010)." Simulation of the emotion dynamics in a group of agents in an evacuation situation". In *International Conference on Principles and Practice of Multi-Agent Systems* 604-619. Springer, Berlin, Heidelberg.

Padma. P. Hirave and Bageshree Pathak. "Fundamentals of active noise control for local cancellation of noise", Institute of Electrical and Electronics Engineers (2011).

Pan, X., Han, C. S., Dauber, K., and Law, K. H. (2007). "A multi-agent based framework for the simulation of human and social behaviours during emergency evacuations", *Ai & Society*, *22*(2), 113–132.

Proulx, G., Laroche, C., and Latour, J. C. (1995). "Audibility problems with fire alarms in apartment buildings". In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 39(15), 989–993. Sage CA: Los Angeles, CA: SAGE Publications.

Proulx, G. (2007). "Response to Fire Alarms", Fire Protection Engineering, 33 (8), 8–14.

Purser, D. (2010). "Comparisons of evacuation efficiency and pre-travel activity times in response to a sounder and two different voice alarm messages". In *Pedestrian and evacuation dynamics 2008*, 121–134. Springer, Berlin, Heidelberg.

Ren, A., Chen, C. and Luo, Y. (2008). "Simulation of emergency evacuation in virtual reality", *Tsinghua Science and Technology*, *13*(5), 674–680.

Struck, C. J. (2019). "Objective Measurements of Headphone Active Noise Cancelation Performance". In *Audio Engineering Society Conference: 2019 AES INTERNATIONAL CONFERENCE ON HEADPHONE TECHNOLOGY*. Audio Engineering Society.

Zhou, J., Jia, X., Xu, G and Jia, J.et al. (2019). "The Relationship between Different Types of Alarm Sounds and Children's Perceived Risk Based on Their Physiological Responses". *International journal of environmental research and public health*, *16*(24), 5091.