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EFFECTS OF EVACUATION SIGN IN A MAZE UTILIZING VIRTUAL REALITY (VR) ON BRAIN WAVES

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ABSTRACT
This study aimed to develop an evacuation sign to ensure people quickly find an exit in smoke and darkness in the early stage of fires, and to measure changes in brain waves in the four areas of the cerebrum (frontal, parietal, temporal and occipital lobes) when people effectively respond to evacuation within the golden time. The frequency of waves observed in the left and right frontal lobes showed that the frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 3.1%, 5.8%, 12.8%, 31.5% and 46.8% respectively. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 3.3%, 5.7%, 12.5%, 40.1% and 38.4% respectively, indicating that the frequency of beta waves increased by 8% and that the frequency of gamma waves decreased by 9%. The frequency of waves observed in the left and right parietal lobes showed that the frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 4.5%, 6.3%, 16.5%, 28.6% and 44.1%. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 4.5%, 6.1%, 15.6%, 41.9% and 32%, indicating that the frequency of beta waves increased by 14% and that the frequency of gamma waves decreased by 13%. The frequency of waves observed in the left and right temporal lobes showed that the frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 3.9%, 7.9%, 13.5%, 30.5% and 44.2%. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 3.5%, 8.9%, 12.9%, 37% and 38.1%, indicating that the frequency of beta waves increased by 7% and that the frequency of gamma waves decreased by 7%. The frequency of waves observed in the left and right occipital lobes showed that the frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 2.5%, 5.1%, 20.1%, 27.1% and 45.2%. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 2.1%, 5.6%, 19.1%, 41.6% and 31.6 %, indicating that the frequency of beta waves increased by 15% and that the frequency of gamma waves decreased by 14%.

KEYWORD: Maze space, evacuation sign, brain wave, gamma wave.

INTRODUCTION
Recently, fires have occurred in places where many people use. The recent fire in a public sports center rapidly spread throughout the entire building due to its piloti structure, and many lives were lost by smoke and toxic gases caused by Styrofoam and exterior materials such as Dryvit prone to fires. Smoke and toxic gases made it difficult to breathe and see ahead. Those who visited the place for the first time were unable to find an exit in the strange place. When a fire occurs in an underground space or a strange space, most people try to find an exit, but various types of smoke and toxic gases emitted from a variety of materials shorten the time for evacuation and even make it difficult to distinguish things in front of them. The golden time for surviving from the occurrence of a fire is 3 minutes.[1] After the golden time, most people end up dead due to difficulty in breathing. This study aimed to develop an evacuation sign to ensure people quickly find an exit in smoke and darkness in the early stage of fires, and to measure changes in brain waves in the four areas of the cerebrum (frontal, parietal, temporal and occipital lobes) when people effectively respond to evacuation within the golden time. Since it is practically impossible to create a fire and smoke in an actual maze for the experiment, virtual reality (VR) with high efficiency and reliability was used to simulate a disaster and their brain waves were measured using a brain wave detector. Brain waves are an electrical flow that transmits signals between cranial nerves in the nervous system. Brain waves are

analyzed by attaching electrodes on the scalp of the cerebrum and extracting signals from the body. Different brain wave signals are observed depending on the conditions of the body including sight, smell, taste, hearing and somatic senses and the conditions of sleep[2,3], and they are used as an important indicator for measuring the activity of the brain depending on the psychological state.

The brain is divided into the frontal, parietal, temporal and occipital lobes, and the frontal lobes control high-level functions such as personality, ethics and the ability to think[4,5], and the parietal lobes control motor skills, the sense of touching and temperature.[6] The temporal lobes control the sense of hearing as well as language skills.[6] The occipital lobes control sight.[7] In this experiment, the Internationally standardized 10-20 System was used. With a tape measure, 4 points from the nasion point to the inion point, and from the preauricular point of the right ear to the preauricular point of the left ear are connected, and electrodes are placed at intervals of 10% and 20% from the central zone (Cz).[8] The 10-20 system is used to analyze and find the location of electrical waves on the scalp of the cerebrum. A total of 19 electrodes were placed on the scalp of the cerebrum, and 2 reference electrodes were attached on the earlobes. Most studies on brain waves conducted a navigation test using a maze to test simple cognitive functions[9,10,11], and there are studies that measured theta waves in the hippocampus related to cognitive behaviors, movement and diet using animals.[12,13] Some studies measured changes in delta waves and hormones to examine the quality and quantity of sleep[14] and beta waves, related to learning and concentration, in the frontal lobes.[4,5] However, there are few studies, like this study, that measured electrical signals generated from the cerebral cortex by the area of the cerebrum depending on the existence of evacuation signs in a maze. Therefore, the evacuation sign developed by the research team of this study is expected to be efficiently used in a public space in a disaster, and to be utilized as basic data, contributing to medical and educational environments as well as daily life.

Experimental Methods

Electroencephalography (EEG)

Electroencephalography (EEG) was first measured by Richard Caton in 1875 in an animal experiment. Since then, a series of studies on changes in the electrical activity of the brain caused by internal and external stimulation have been published.[15] Hans Berger first discovered alpha rhythm and alpha block in the human body in 1929.[16] Brain waves are divided into delta, theta, alpha and beta waves depending on the frequency of signals and are activated by a variety of activities (Table 1).

Table 1. Wave of EEG (Electroencephalography).

Wave	Hertz	Function
Delta, δ	1~4Hz	Deep sleep, brain malfunction etc.
Theta, θ	4~8Hz	Light sleep, etc.
Alpha, α	8~13Hz	Arousal, etc.
Beta, β	13~30Hz	Arousal, muscular activity, stress, etc.
Gamma, γ	31~100Hz	Severe stress, urgent situations, etc.

EEG Analysis: The electroencephalography (EEG) of the subjects was measured using an EEG headset called Quick-20 (PELICAN PRODUCTS TORRANCE CA, USA) that supports the International 10-20 System (Figure 1) (Figure 2).

EEG analysis was performed by analyzing electrical signals generated from the frontal, parietal, temporal and occipital lobes depending on the use of an evacuation sign in a maze.

The sampled frequency was 0.3~100 Hz and 60Hz was selectively blocked. The low-frequency and high-frequency filter was 0.3~100 Hz, and the setting conditions for EEG analysis were as follows: 8 channels, 5mm/50μV sensitivity.

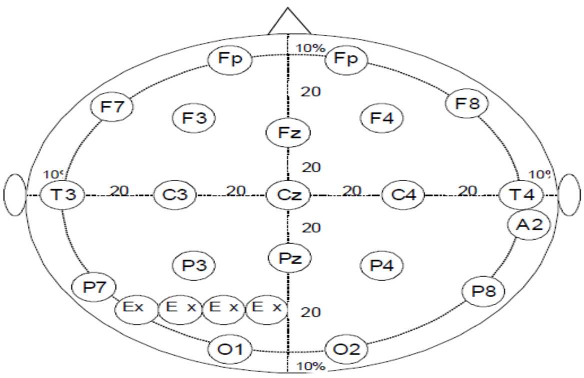

Figure 1. Internationally Standardized 10-20 System.

Abbreviations: odd number, the left hemisphere of the brain: even number, the right hemisphere of the brain, Fp, Frontal-pole: F, frontal: C, central:, P, parietal: O, occipital: A, auricular.

Figure 2. EEG headset 'Quick-20' (Pelican Products Torrance CA, Usa).

Figure 3. VR device (HTC VIVE Pro Virtual Reality Headset htc).

The VR device (HTC VIVE Pro Virtual Reality Headset htc) in Figure 3 was used in this study.

-0 sec, starting point -After 32 sec, mid-point -After 70 sec (suffocation expected)

Figure 4. VR navigation test in a maze without an evacuation sign.

Figures 4 show the example of a subject who failed to find an exit in the VR navigation test in a maze without an evacuation sign.

-0 sec, starting point -After 17 sec, mid-point -After 42 sec (suffocation expected)

Figure 5. VR navigation test in a maze with an evacuation sign.

Figures 5 show the example of a subject who found an exit in the VR navigation test in a maze without an evacuation sign in 42 seconds.

Subjects

This study was conducted among a total of 45 young adults (23 males, 22 females) aged between 20 and 26. They were fully informed of this experiment and signed a consent form for participation prior to this experiment. Through a pre-survey questionnaire, those who had brain diseases, breathing disorders, claustrophobia, dizziness or tinnitus over the past 6 months before this experiment were excluded. The following items were surveyed: fire experience; VR game experience; ways to obtain information on methods for evacuation to protect themselves in a disaster; experience of receiving education on evacuation upon the occurrence of a fire; whether they knew the golden time for evacuation from a fire is less than 3 or 4 minutes; whether they knew the characteristics and danger of smoke caused by a fire; evacuation positions and ways to evacuate and survive from smoke caused by a fire; whether they knew emergency exits and evacuation signs in underpasses or subways; whether they identified emergency exits and evacuation signs; experience of assuming the occurrence of a fire and disaster and simulating evacuation; whether they assumed the occurrence of a fire and identified a safe space for evacuation; and elements of evacuation signs that are easy to find in an emergency situation. This experiment was performed according to the research ethics.

Statistical Analysis

Data obtained from this experiment were statistically analyzed using SPSS version 21, and Table 3 shows the results of a paired t-test. Figure 6 shows the results of an independent t-test on each variable.

RESULTS AND CONCLUSIONS

Table 2 shows the general characteristics of the subjects. Their average age was 20∽26 years, and 23 males and 22 females participated in this experiment. About 89% of the subjects did not have any dizziness and 92% did not have an experience of claustrophobia. Only one of the subjects (2.2%) had experience of a fire, and about 47% had experience of a VR game.

About 89% of the subjects answered that they had no experience of simulating a fire, and 67% answered that they knew the golden time for evacuating from a fire is 3 minutes. About 78% of the subjects knew emergency exits in the underpasses they frequently used, but only 5% recognized evacuation signs.

Roy[17] found that cognition and judgement were reduced by about 18% in an unstable situation compared to a stable state in an early Alzheimer mouse model. Only 5% of the subjects knew the location of emergency exits in the subways and underpasses that they frequently used, which indicates that it will take more time for them to find an evacuation exit upon the occurrence of a fire than usual as they may be in a state of panic. Table 3 shows similar results.

Table 2. Summary of subjects.

Description			N (total=45)	%
Demographic Characteristics	age	20-26	45	100
Demographic Characteristics	sex	male	23	51.1
Demographic Characteristics	sex	female	22	48.9
Disease History	encephalopathy	no	45	97.8
Disease History	encephalopathy	yes	1	2.2
Disease History	dizziness	no	40	88.9
Disease History	dizziness	yes	5	11.1
Disease History	respiratory disturbance	no	42	93.3
Disease History	respiratory disturbance	yes	3	6.7
Disease History	claustrophobia	no	41	91.1
Disease History	claustrophobia	yes	4	3.9
Experiential aspect	fire	no	44	97.8
Experiential aspect	fire	yes	1	2.2
Experiential aspect	VR game	no	21	46.7
Experiential aspect	VR game	yes	23	53.3
Experiential aspect	evacuation simulation	no	40	88.9
Experiential aspect	evacuation simulation	yes	5	11.1
Preparation for accident	cognition of fire golden time (3 min.)	no	30	66.7
Preparation for accident	cognition of fire golden time (3 min.)	yes	15	33.3
Preparation for accident	cognition of emergency exits	no	9	22.2
Preparation for accident	cognition of emergency exits	yes	36	77.8
Preparation for accident	cognition of safe place	no	32	71.1
Preparation for accident	cognition of safe place	yes	13	28.9
Preparation for accident	cognition of evacuee guidance	no	43	95.6
Preparation for accident	cognition of evacuee guidance	yes	2	4.4

Abbreviations: VR, Virtual Reality

Table 3. 2-paired t-test according to the taxiway line status.

group	Mean ± S.D. (sec)	t	significance probability
Pre	84.01 ± 10.27	9.64	0.00
Post	56.26 ± 13.98	9.64	0.00

Abbreviations: Pre, pretest not with taxiway line status; Post, postest with taxiway line status; S.D., standard deviation

Table 3 shows the results of a t-test on the time for evacuation in a maze depending on the existence of evacuation signs. The time for evacuation in a maze without an evacuation sign was 84.01 ± 10.27 sec, while that for evacuation in a maze with an evacuation sign was 56.26 ± 13.98 sec, down by 27 seconds. As Figure 4 (without an evacuation sign) and Figure 5 (with an evacuation sign) above showed, the subjects answered in the post-experiment interview that evacuation signs, especially yellow signs, were helpful for them to calmly find an exit even in smoke caused by a fire.

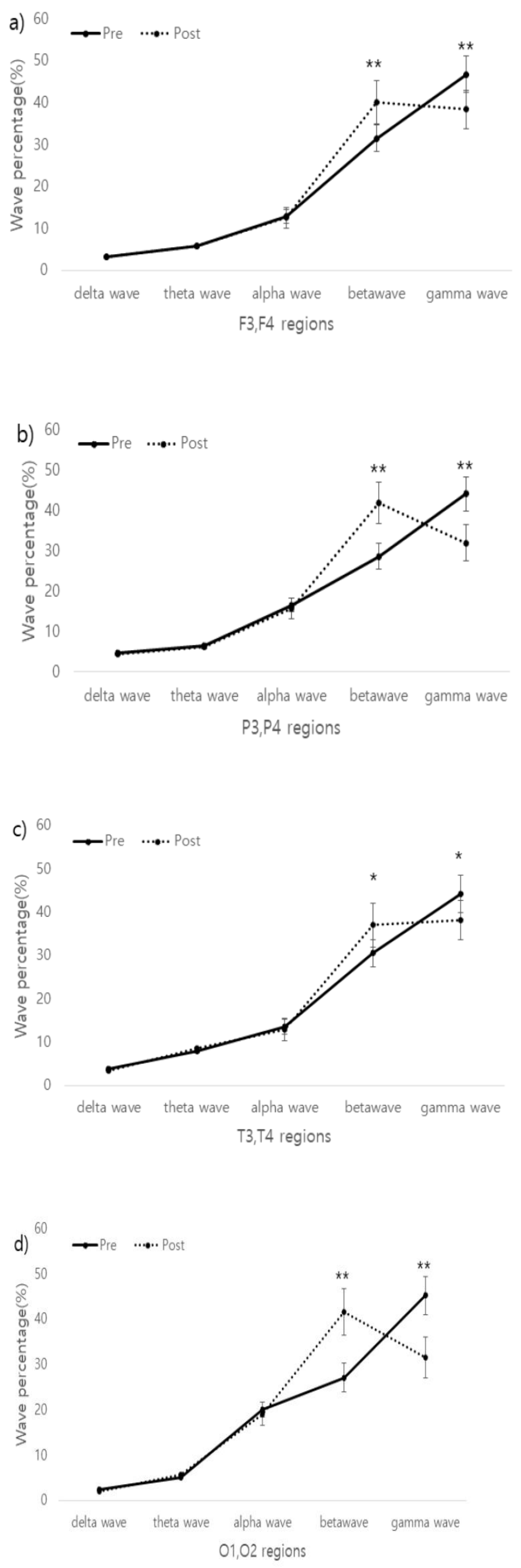

Figure 6. Illustration of Absolute Power of electrodes. (a)F3, F4 (b) P3, P4 (c) T3, T4 (d) O1, O2. Beta and gamma waves in a): p=0.006, p=0.004; Beta and gamma waves in b): p=0.005, p=0.003, Beta and gamma waves in c): p=0.023, p=0.028, Beta and gamma waves in d): p=0.008, p=0.007.

Figure 6 shows the frequency of waves observed in the frontal, parietal, temporal and occipital lobes of the cerebrum.

Figure 6 a) shows the frequency of waves observed in the left and right frontal lobes. The frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 3.1%, 5.8%, 12.8%, 31.5% and 46.8% respectively. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 3.3%, 5.7%, 12.5%, 40.1% and 38.4% respectively, indicating that the frequency of beta waves increased by 8% and that the frequency of gamma waves decreased by 9%. Figure 6 b) shows the frequency of waves observed in the left and right parietal lobes. The frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 4.5%, 6.3%, 16.5%, 28.6% and 44.1%. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 4.5%, 6.1%, 15.6%, 41.9% and 32%, indicating that the frequency of beta waves increased by 14% and that the frequency of gamma waves decreased by 13%. Figure 6 c) shows the frequency of waves observed in the left and right temporal lobes. The frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 3.9%, 7.9%, 13.5%, 30.5% and 44.2%. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 3.5%, 8.9%, 12.9%, 37% and 38.1%, indicating that the frequency of beta waves increased by 7% and that the frequency of gamma waves decreased by 7%. Figure 6 d) shows the frequency of waves observed in the left and right occipital lobes. The frequency of delta, theta, alpha, beta and gamma waves when there was no evacuation sign was about 2.5%, 5.1%, 20.1%, 27.1% and 45.2%. The frequency of delta, theta, alpha, beta and gamma waves when there was an evacuation sign was about 2.1%, 5.6%, 19.1%, 41.6% and 31.6 %, indicating that the frequency of beta waves increased by 15% and that the frequency of gamma waves decreased by 14%. Brain waves significantly change while finding an exit route in virtual reality (VR)[18], and theta waves increase in the entire cerebrum once people start to find an exit route in a maze.[16,19] As discussed above, alpha and theta waves are normally observed in the entire cerebrum in daily life. In this experiment, however, theta waves decreased when there is no evacuation sign, while gamma waves that are observed in a state of panic or danger with a very low amplitude increased. A continuous increase in gamma waves is known to have a harmful influence on mental health, causing schizophrenia[20,21,22] and short-term amnesia.[23,24,25] However, when there was an evacuation sign, theta waves increased and gamma waves that are observed in a state of danger decreased, indicating that the subjects seemed to try to find an exit by simulating a way to safely escape the situation with the help of the evacuation sign.

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