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A Learning Attention Improvement System Based on Neuro Feedback

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Abstract: This study introduces a neurofeedback based learning attention improvement system. This aims to allow normal people to take concentration tests in an affordable and convenient way without visiting a medical institution. To achieve this, we defined the learning attention brainwave and used it to analyze whether students were concentrating on their task or not. We designed a neurofeedback based learning attention training program based on these results which monitors and provides feedbacks to users. Furthermore, we designed to use a Virtual Reality Head-Mounted Display (VR-HMD) to maximize the effectiveness of the training by drawing user's attention. Unlike conventional attention improvement services based on neurofeedback which control overall brain functions and do not focus on learning attention, our suggesting system thoroughly focuses on attention optimized for effective learning. Our system also provides users with customized learning attention training contents based on their learning attention level with a more precise approach compared to other existing systems which provide the same content to all users. The most unique point of our system is its utilization of VR and HMD as a display tool for training contents. VR and HMD attract user's attention quickly and effectively and therefore it can contribute to maximize the effect of the training content we provide to students. To verify the system, we conducted flow assessment for high school and college students after finishing a demonstration and short presentation. Most respondents replied affirmatively in more than 78% of questions and expectation for actual commercialization was highest among high school students.

Key words: Learning attention, concentration improvement system, EEG, brainwave analysis, virtual reality, Korea

INTRODUCTION

Brainwaves are defined as continuous electrical pulses which are produced when neurons in the brain communicate with each other (Phneah and Nisar, 2017). When human beings think or act, the synapses in the brain communicate information using neuroelectric substances (Alivisatos *et al*., 2013). At this point, the current flow is caused by a potential difference between the neurons. Current flow can be measured through electrodes placed on the scalp. Brainwaves have been widely used in clinical trials and studies of brain function after first being discovered by German scientist Hans Berger in 1929 and Morris (1990). They are a very important biological signal that shows human brain activity and are used to diagnose cerebral diseases through measurement and analysis (Ridouh *et al*., 2017). Brainwaves are produced constantly and their frequency implies what kind of activities the brain is currently engaged in and how intensively it is working. Brainwaves are divided according to brainwave frequency into five groups: delta waves (1-4 Hz), theta waves (4-8 Hz), alpha waves (8-13 Hz), beta waves (13-30 Hz) and gamma waves (30-120 Hz) (Mirowski *et al*., 2009). Alpha waves are generated when a person is relaxed with eyes closed and thinking creatively (Cho *et al*., 2011). Beta waves are produced when a person is conscious, awake and nervous or tense (Chen *et al*., 2017). Theta waves occur when a person feels sleepy or is deeply meditating (Fahrion *et al*., 1992). Delta waves imply that a person is sleeping. If delta waves are detected from a person who is awake, this indicates the likely presence of a brain tumor or encephalitis (Cimini *et al*., 2008). Brainwaves are very feeble electrical signals that vibrate <50 times a second. Moreover, they are difficult to measure because they are greatly influenced by the locations of electrodes and external environments (Sun, 2014). Brainwaves measured through electrodes are sent to an amplifier and then

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undergo the AD transformation process. In this stage, brainwaves are converted from an analog to a digital form to facilitate analysis. This also requires noise removal to eliminate noise data (Srinivasan and Reddy, 2010). Electrodes are placed according to the international 10-20 system. This standard was proposed by Jasper in 1985 and indicates where to attach electrodes on the human scalp. It does not state absolute location but rather comparative location based on distance between points. General Electroencephalogram (EEG) tests administered by medical staff in medical institutions use 23 electrodes to measure brainwaves (Myslobodsky *et al*., 1990).

In the past, body functions controlled by the autonomic nervous system such as brainwaves were believed to be beyond our control and will. However, in the 1950's, Dr. Miller of Yale University discovered that muscles and autonomic nervous systems such as muscles of the heart and internal organs can be also controlled by our will to control ourselves. Biofeedback technology is a technique that allows us to control these kind of involuntary muscles or the autonomic nervous system (McManus, 1996). The word 'neurofeedback' combines 'neuro-' which means 'nerve' with 'feedback' from the word 'biofeedback' (McManus, 1996). Neurofeedback is currently starting to be used in various field. For example, neurofeedback technology is used in sports which requires momentary high concentration, to analyze athlete's psychological status to dispel anxiety and increase concentration by generating positive brainwaves (Dupee and Werthner, 2010). Neurofeedback technology is also employed to treat Attention Deficit Hyperactivity Disorder (ADHD) patients. ADHD patients are treated typically treated with medication, however, side effects such as insomnia, lack of appetite and growth retardation are a concern. Neurofeedback-based treatments show similar treatment outcomes compared to typical treatments using medication. In addition, neurofeedback pursues fundamental changes in ADHD treatment by make patients improve their brain function, in contrast to typical treatments using medication which only suppresses symptoms which can happen again if the patient stops taking medication. For these reasons, neurofeedback technology is widely considered as an alternative to medication-based treatments (Rubia *et al*., 2017).

Many researchers claim that the neurofeedback training is equally or more effective compared to medication when treating children with ADHD. Attempts to treat the ADHD children with neurofeedback training are increasing and report positive results in Republic of Korea.

However, EEG tests and devices are very expensive and thus their accessibility to ordinary people is limited. However, recent advances in brainwave measurement technologies have led to the release of a variety of low-cost, comparatively high-quality brainwave measuring devices. Various studies utilizing these devices have been conducted in an effort to improve normal people's quality of life based on their brainwaves (Ellenbogen, 2004). The speech-generating device which Dr. Stephen Hawking uses to communicate with people is one of the most well-known examples of Brain-Computer Interface (BCI) technology in which people control computers with only their brainwaves. This device called 'iBrain' was developed in 2012 by Dr. Philip from Stanford University. It reads human brainwave activity to discern 'intention' and transmits it wirelessly back to a computer to make commands such as input words and file access. This device contributes considerably to Dr. Hawking's ability to continue his research (Rojas *et al*., 2016). Similar BCI technology has been adopted by people with physical disabilities and patients who have prosthetic implants to help them communicate with the world. Furthermore, greater efforts are being put forth to adopt these technologies into the general public's way of life (Mori *et al*., 2011). The rapid evolution of artificial intelligence and big data technology are accelerating the speed of brainwave-based technology adoption into everyday life.

Another recent noteworthy technology is Virtual Reality (VR). VR means artificial environments which are very similar to real environments. Users can experience virtual reality through a combination of images, sounds and other sensations that simulate those of the real environments they mimic (Stein, 2016). They provide stimuli directly to users and users feel that they are really interacting with virtual features of items. Virtual reality normally uses a Head-Mounted Display (HMD) so, users can look around within the artificial world. These devices immerse users in the VR world's content more readily than traditional displays such as computer screen monitors (Mukherjee *et al*., 2016). The current price of HMD which is necessary to fully experience virtual reality has dropped considerably, since, its first appearance it is now expected to be useful within everyday life and contribute to improving people's quality of life.

This study introduces a neurofeedback-based learning attention improvement system which allows people to measure and analyze their brainwaves to cheaply and easily improve their ability to study. For this, we used a new brainwave called 'Learning Attention Brainwave' (LABW) which focuses attention on learning rather than other stimuli. We also utilize virtual reality and HMD as a training content display tool to maximize user attention.

We conducted flow assessment of high school and college students after finishing a demonstration and short presentation to verify the system. Most respondents replied affirmatively to more than 78% of questions and expectation of actual commercialization was highest among high school students.

Literature review

Attention and brain: The human brain is divided into regions responsible for different roles (Gibbons, 1990). Many studies have been conducted to investigate correlations between various brain activities such as concentration and brain regions. Lack of concentration can be seen as a symptom of deficiency in a specific brain region, the frontal lobe which regulates and controls stimulation (Kirsch *et al*., 2004). A person with frontal lobe deficiency has difficulty sustaining attention, easily loses concentration and is distracted. He or she also has difficulties in planning and organization along with fluctuating emotions because the frontal lobe of the brain is responsible for these.

The occipital lobe is at the rear of the cerebral cortex and integrates and analyzes visual information. Information processed from the occipital lobe is transmitted through either the dorsal or ventral path (Gibbons, 1990). The dorsal path handles visual information such as location, speed and distance while the ventral path, handles judgment and long-term memory storage are comparing the colors and shapes of things which the person see now with existing memories. Throughout most learning processes, we accept information visually and all of the information is processed and stored in the occipital lobes. According to a variety of studies analyzing gifted student's brains, the brain regions of gifted students interact much more than those of normal students. When researchers give them the same questionnaires, the regions of gifted student's brains tend to actively interact, especially, the frontal and occipital lobe in contrast to normal students. This implies that active interaction between the frontal lobe and the occipital lobe is strongly related with a student's cognitive abilities. Students who have high fluid intelligence such as inference or calculation abilities also tend to show more interaction between the frontal lobe and the occipital lobe. Students with highly developed occipital lobes are typically highly intelligent.

Attention and brainwaves: There have been many studies investigating the relationship between attention ability and brainwaves. Brainwaves can normally be classified into 6 groups including alpha, beta waves and Sensorimotor Rhythm (SMR) between alpha and beta waves which has been revealed to be related to human attention. With this exception, there is currently much research classifying and defining brainwaves according to their specific purposes.

Alpha waves: Alpha waves have a frequency of 7-14 Hz and typically represent 50% of human brainwaves per day. They are a present when a person is physically and mentally calm. Human brain activity is most active when alpha waves are being generated, including attention ability, memory and cognitive skills. Therefore, eminent scientists and mathematicians who have made great discoveries have often done so at rest in places with no relation to their studies. These brainwaves are generated when a person is relaxed. Someone who can control alpha waves as he or she wishes can show his or her ability in work and think creatively.

Beta waves: Beta waves are brainwaves which are within the range of 14-30 Hz. They appear when a person is very tense or excited with a high level of stress. Beta waves are generated when the brain must process information and help the brain process the work effectively. However, if they are generated for too long, a person's emotional excitement will reach its limit, bringing him or her into conflict with others and extinguishing memories. Additionally, excessive creation of beta waves is correlated with all sorts of adult diseases such as cancer, gastric ulcers, duodenal ulcers, lack of immune function, hypertension, diabetes, etc. In this case, treatment may be necessary to artificially suppress the generation of beta waves in favor of alpha waves to prevent illness and sustain health.

SMR (Sensorimotor Rhythm): Sensorimotor Rhythm (SMR) is within 12-15 Hz. It was discovered by Dr. Barry Sterman at UCLA. SMR is found in the sensory cortex and the motor cortex of the cerebral cortex and the range of waves is located between that of alpha and beta waves. Sensorimotor rhythm appears when a person conducts a task accurately without mistakes. Unlike beta waves, SMR does not lead to stress and the body does not become tense. SMR waves are much more concentrated than beta waves and help a person solve problems with very little energy. SMR waves are being used in various fields such as attention training for US Air Force pilots and spaceship pilots in the US National Aeronautics and Space Administration, medical care, psychological therapy, improving athlete's athletic skills and stress therapy for business people.

Table 1: ATA evaluation tool scoring index

Variables	Definition
Attention dispersion	How many target stimuli did the subject miss?
Impulsive behavior	How many non-target stimuli did the subject react to?
Information processing Speed	Average response time to stimuli
Attention consistency	Standard deviation in stimulus response time

LABW (Learning Attention Brainwave): The Learning Attention Brainwave (LABW) measures and analyzes only the attention associated with learning. Learning attention means the ability to proactively identify task priorities and tries to maintain focus on the task which is classified as the most important task even if the person does not want to. In other words, learning attention means the ability to maintain attention on the task currently deemed most important. The learning attention brainwave is a criterion to judge attention while learning.

Electroencephalograms (EEG): Electroencephalograms (EEG) measure electrical pulses from the human scalp and are within the range of 0.1-120 Hz. They show the total information of electrical pulses resulting from the activity of nerve cells in the brain. Brainwave classifications appear in Table 1.

Brainwaves are continuous and their frequency varies depending on which activity the person is doing and how intently they are doing it. Brainwaves are generally classified according to frequency into delta waves, theta waves, alpha waves, beta waves and gamma waves. Alpha waves are generated when a person closed his or her eyes and is comfortable and when a person focuses on something or thinks creatively. Beta waves appear when a person is highly stressed and does hard physical exercises or is in a state of intense concentration. Theta waves are generated when a person feels sleepy or is meditating. Delta waves are normally generated then a person is in a deep sleep however, they are occasionally present when the person is awake. This indicates the strong possibility of a brain tumor. EEG devices are a noninvasive way to measure brainwaves. Their data is highly reliable and because of their simplicity and low price compared to other methods such as fMRI, they are widely used in medical institutions. However, refining and transforming the original raw data from EEG signals is very complicated and difficult because brainwaves are very weak electrical signals which vibrate under 50 times per a second.

EEG results are affected by external environments such as heart rate and blinking therefore, much effort is required to interpret brainwaves. First, measured brainwaves are amplified by an amplifier attached beside the electrode attached to the human scalp to detect brainwaves. Amplified signals are then transmitted via. AD transformation which transforms analog digital data. Noise is removed to refine the data which can finally be classified and analyzed by researchers. 23 electrodes are normally placed on the human scalp to detect brainwaves and are placed in accordance with the widely accepted international 10-20 system. The international 10-20 system uses distance between reference points rather than absolute location to place the EEG sensors. Although, 23 sensors are normally used on the scalp to detect every brainwave signals generated from the brain, the researcher may use only a few sensors in relevant locations if he or she wishes to analyze a specific region of the brain.

Neurofeedback: Neurofeedback is a type of biofeedback technology in which humans control their brainwaves at will. It indicates to a person what kind of brainwaves are being generated in his or her brain based on detected and analyzed brainwaves. If the user sets a specific range of brainwaves, the neurofeedback training system informs the user whether that brainwave is detected from his or her brain or not and the user automatically tries to keep getting positive feedback from the neurofeedback training system. Through these processes, the user can strengthen their desired brainwaves and gradually develops the ability to control them similarly to the conditioned reflexes discovered by Pavlov.

In 1971, Dr. Berry Sterman succeeded in treating epilepsy patients using a neurofeedback training program and sensorimotor rhythms. In 1976, Dr. Lubar at the University of Tennessee accomplished ADHD and ADD treatment through a neurofeedback training program using SMR waves and beta waves. After consecutive reports of neurofeedback-based treatment success both in the field of physical illnesses as well as that of psychological disabilities such as depression, neurofeedback training programs are increasingly used to treat patients. However, neurofeedback training is still limited in its use by medical staff and institutions because of its high cost and the difficulty of interpreting results.

EEG devices for the general public are currently available on the market at an affordable price. Accordingly, there are more and more efforts made to apply EEG-based neurofeedback to improve intelligence, learning ability, working skills and performance skills. These emerging efforts aim to maximize the general public's cognitive abilities to prevent psychological and other diseases related to brain aging and function. The human brain is continuously changing depending on a person's status and environment and therefore, if we stimulate the brain adequately, it can be changed in positive ways. In reality, neurofeedback training programs have proven very effective in developing the cognitive abilities of healthy and normal people, especially children and teenagers experiencing brain growth. However, this is of use not only to teenagers but even to adults whose brains have fully developed. This study focused on maximizing the cognitive abilities of teenagers as well as adults by developing a model for learning attention skills to enhance learning attention.

Traditional attention mearusrement tool: The ATA is an evaluation tool to diagnose ADHD in young children. Professors at Seoul National University developed this test by refining typical attention ability evaluation questionnaires. It evaluates selective attention ability and impulse control ability in young children by providing the subject with a target stimulus and non-target stimulus randomly one at a time. The subject should react only to the target stimulus seen before starting the test. After finishing the test, the results can be scored according to an internal index. An expert can judge whether or not the subject has ADHD based on his or her score and also provide information on the subject's score compared to other subjects of the same age group.

Traditional tools for measuring and testing concentration include Frankfurter Aufmerksamkeits Inventar (FAIR) which is administered by the Board of Education to mentally deficient students; Bender Gestalt Test (BGT) which provides nine shapes and ask the subjects to copy them; Home, Tree, Person (HTP) which inspects mental state and attention through house, person and tree drawings; and Kinetic Family Drawing (KFD) which examines family perception and concentration through family drawings. Most of these tests have the advantage of being easy to conduct any time, anywhere regardless of the subject's age as long as the subject can communicate with the expert. However, a limitation of these tools is that they heavily rely on medical staff opinion rather than objective indicators (Table 1).

F. Virtual Reality (VR): Virtual Reality (VR) is an artificial environment that resembles reality. It is a technique that enables users to experience realistic spatial and temporal experiences by stimulating all five senses. This allows users to interact with lifelike environments and achieve extreme immersion. Virtual reality enables three-dimensional spatial and real-time interaction with a computer and is possibile because of developments in computer graphics, network communication and HMD technologies. The use of HMD is particularly essential to experience virtual reality. Although, there was a fairly high price barrier when it was new on the market, it is now expected to be used by general users as they are now able to purchase relatively low-cost devices to upgrade their quality of life. This study suggests that the use of virtual reality and HMD to display the training content will maximize the effectiveness of the learning attention training by providing differentiated immersion to improve learning attention.

MATERIALS AND METHODS

Proposed system

Neurofeedback based learning attention improvement system: This study proposes a neurofeedback-based learning attention improvement system. Existing traditional concentration tools are limited by their lack of objectivity, relying too much on expert opinion.

In addition, there are doubts about the actual effectiveness of these attention evaluations when it comes to attention specifically for learning. Therefore, the model proposed by this study used the learning attention brainwave which focuses on attention while learning, along with brainwave analysis-based neurofeedback to overcome the limitations of traditional tools. It also provided customized learning attention training content based on the learning attention level of the subject and these training programs were displayed through VR and an HMD. This has the advantage of maximizing the user's ability to focus on content by maximizing the user's degree of immersion compared to conventional displays (Fig. 1).

Learning attention improvement system: We focused on allowing users to monitor and train their brain routinely, easily, cheaply and objectively. In the same vein, unlike conventional studies employing 23 electrodes, we designed ours to use only 4 electrodes. The electrodes were attached to two sites on the Frontal lobes (FP1, FP2) and another two sites on the Occipital lobes (O1, O2) with electrode attachment locations based on the international 10-20 system. EEG tests generally involve placing 23 electrodes on the scalp to measure all brainwaves generated from the brain but this study solely focuses on attention while learning and thus 2 electrodes at each site were attached to the Occipital lobes (O1, O2) and the Frontal lobes (FP1, FP2). According to the international 10-20 system manual, the number of electrodes attached to the scalp can be adjusted depending on the reason for measuring the brainwave as long as electrodes are placed on the proper locations.

The measured brainwaves were used to determine whether the subject was focusing on learning through the results of the processing, refining and analysis stages.

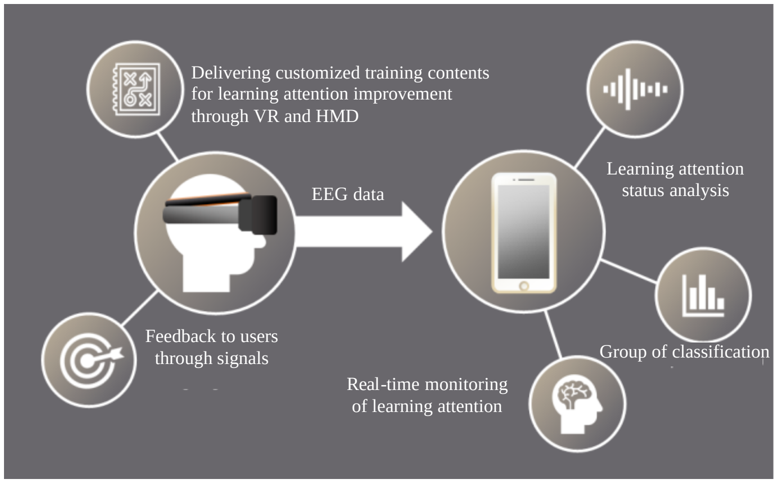

Fig. 1: Neurofeedback based learning attention improvement system

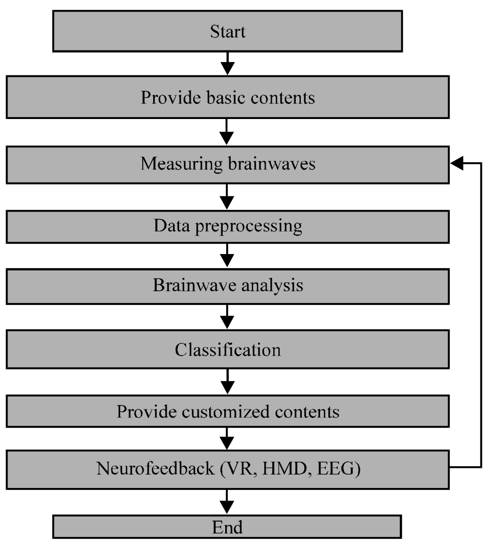

Fig. 2: System flow of the neurofeedback based

This was monitored in real time and the analysis results were fed back to the user in real time. Users could view or listen to this feedback and carry out neurofeedback training more effectively to improve learning attention. Through all stages stated above, the subject continuously tries to generate learning attention brainwaves and in conclusion, the subject can control his or her brainwaves and generate learning attention brainwaves at will. The system flow of our suggested neurofeedback program is as follows (Fig. 2).

Verification: We conducted a flow evaluation to validate the proposed model. The validation was conducted shortly after a brief demonstration of this model. The answer sheet included 5 responses: 'strongly disagree', 'disagree', 'no neither agree nor disagree', 'agree' and 'strongly agree' based on the Likert scale. The questionnaire comprised the understanding of the system proposed by this study how strongly this system would motivate you, the usability of this system and intention to purchase the system if actually released on the market.

Both high school and college students replied affirmatively to the questions and could confirm their expectation and confidence in the system proposed by the study. The high school student group in particular expressed their expectations and asked for our launch plan. However, some students responded "neither agree nor disagree" or "disagree" due to their own economic circumstances to the question asking if they would be willing to spend their own money on this system if released on the market.

Questionnaire for efficiency evaluation:

- I can focus on the content while wearing an HMD
- I will get better results from training using an HMD
- Controlling a VR device is easy
- Using this system would improve my learning attention
- I became interested in the system after experiencing it
- I intend to buy this system if it is released on the market

The efficiency evaluation included 10 high school students and 10 college freshmen, a total of 20 students. Figure 3 shows a graph of 'agree' or 'strongly agree in each questionnaire. This confirms that high school

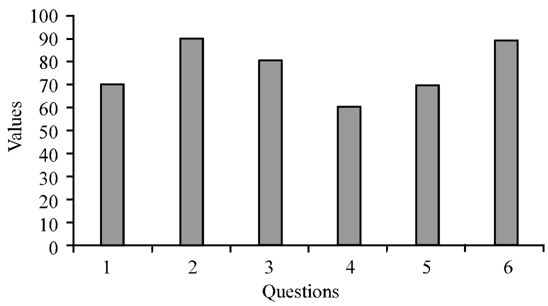

Fig. 3: The results of the flow assessment

students and college students responded affirmatively. However, question number 6 of the survey showed relatively low responses. This is because the survey participants were teenagers and twenties and they were not executing economic activities. However, since, the positive answer to question number 4 was more than 90%, the students will likely be willing to purchase them if they become economically qualified. Overall, it was found that high school students and college students had high expectations of the effectiveness of their learning attention through this system.

RESULTS AND DISCUSSION

This study suggested a neurofeedback based learning attention improvement system. This system was intended to overcome the limitations of typical existing evaluation tools such as lack of objectivity, a broad view of the concept of attention rather than specifically ‘learning’ and expensive one-time tests which prevent students from checking changes in their attention over time.

The system we propose in this study utilizes learning attention brainwaves which are optimized for learning, measures brainwave with only four EEG sensors placed on the frontal and occipital lobes and implements neurofeedback training. Learning attention training content is customized according to the level of learning attention and provided through VR which maximizes immersion in the training concepts to result in maximum improvement.

This system is expected to achieve the most drastic positive change when it is used by growing children and teenagers because their brains are still growing and stimuli can easily be changed. Adults whose brain development has already finished can also expect some development in their brain ability as the human brain changes continually depending on a person’s physical and mental status and the system can also help prevent brain aging. This neurofeedback-based learning attention improvement program can also help to prevent diseases or symptoms such as dementia which are closely correlated with brain aging.

This system received favorable responses from high school and college students based on flow assessment results. High school students in particular expected it to be released on the actual market.

This system has some differences from related systems. First, we utilized not just alpha waves and SMR which relate to the broad concept of attention but ‘learning attention brainwaves’ which are attention optimized for learning. Second, unlike other existing systems which provide the same content to all students, we designed this system to provide content appropriate for each person’s level of learning attention. This will increase the effectiveness of the training because every student can be provided with adequate content suitable for him or herself. Finally, we designed the system to provide training content through virtual reality and a head-mounted display to maximize student’s immersion. This increases both interest in the training content and the training outcome.

We tried to develop a neurofeedback-based learning attention improvement system in a comparatively scientific way. We analyzed existing research and services and designed a system to overcome their limitations. However, as this system is new, it also has its limitations and we therefore suggest that future research would be beneficial. The first limitation is that this study verified the effectiveness through comparatively few students and thus is difficult to generalize. Therefore, extensive sample data construction, clinical trials and expert validation are required to more precisely verify the system’s effectiveness. Second, it will be necessary to extensively develop learning attention training content to provide more diverse and more suitable content to students.

CONCLUSION

Although, this study utilizes content that can cover all age groups, it would be advantageous to expand the training content to consider age, gender, academic background and level and interest of the subjects. This newly-provided content could then be verified again.

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