RESEARCH PAPER

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eISSN 2093-758X
J Korean Acad Nurs Vol.52 No.1, 36
https://doi.org/10.4040/jkan.21155

Effects of Electroencephalogram Biofeedback on Emotion Regulation and Brain Homeostasis of Late Adolescents in the COVID-19 Pandemic

Park, Wanju · Cho, Mina · Park, Shinjeong

College of Nursing, Kyungpook National University, Daegu, Korea

Purpose: The purpose of this study was to examine the effects of electroencephalogram (EEG) biofeedback training for emotion regulation and brain homeostasis on anxiety about COVID-19 infection, impulsivity, anger rumination, meta-mood, and self-regulation ability of late adolescents in the prolonged COVID-19 pandemic situation. **Methods:** A non-equivalent control group pretest-posttest design was used. The participants included 55 late adolescents in the experimental and control groups. The variables were evaluated using quantitative EEG at pre-post time points in the experimental group. The experimental groups received 10 sessions using the three-band protocol for five weeks. The collected data were analyzed using the Shapiro-Wilk test, Wilcoxon rank sum test, Wilcoxon signed-rank test, t-test and paired t-test using the SAS 9.3 program. The collected EEG data used a frequency series power spectrum analysis method through fast Fourier transform. **Results:** Significant differences in emotion regulation between the two groups were observed in the anxiety about COVID-19 infection (W = 585.50, p = .002), mood repair of meta-mood (W = 889.50, p = .024), self-regulation ability (t = – 5.02, p < .001), self-regulation mode (t = – 4.74, p < .001), and volitional inhibition mode (t = – 2.61, p = .012). Neurofeedback training for brain homeostasis was effected on enhanced sensory-motor rhythm (S = 177.00, p < .001) and inhibited theta (S = – 166.00, p < .001). **Conclusion:** The results demonstrate the potential of EEG biofeedback training as an independent nursing intervention that can markedly improve anxiety, mood-repair, and self-regulation ability for emotional distress during the COVID-19 pandemic.

Key words: Biofeedback; Emotional Regulation; Anxiety; Adolescent; COVID-19

INTRODUCTION

In the fourth industrial revolution era of the 21st century, there has been increasing interest in the brain science. The recent Coronavirus Disease 2019 (COVID-19) pandemic has caused much fear due to the uncertainty, universality, and unpredictability of outbreaks. This fear is not limited to physical infection problems, but also includes threats to mental health, leading to negative psycho-emotional experiences such as corona blue or corona red with unstable brain function [1,2]. The coronavirus has affected everything in our day-to-day lives including work, school, routines, and mental health.

In the COVID-19 situation, 41.9% of the general public has experienced uncomfortable thoughts about the coronavirus. More than a third (35.6%) reported feeling nervous or anxious when watching the news about COVID-19 on social networks [3]. Cao et al. [4] found that 24.9% of medical students were afflicted with anxiety due to the COVID-19 outbreak, while Park et al. [5] reported that late adolescents experienced more anxiety about COVID-19 infection than Ebola or H1N1 virus infection.

*This work was presented at Summer Academic Conference of Korean Academy of Forensic Nursing, July, 2021, Daegu, Korea.

Address reprint requests to : Park, Shinjeong

College of Nursing, Kyungpook National University, 680 Gukchabosang-ro, Jung-gu, Daegu 41944, Korea

Tel: +82-53-420-4977 Fax: +82-53-255-4977 E-mail: chocho0129@naver.com

Received: August 4, 2021 Revised: October 28, 2021 Accepted: December 6, 2021 Published online February 28, 2022

Despite active psychological quarantine support, late adolescents are concerned about the long-term impact of blind spots. Khan et al. [6] and Pedrosa et al. [1] reported that late adolescents are vulnerable to a psychological impact due to major changes in their routine school life, since schools were temporarily closed, and events such as study exchanges and graduation ceremonies were postponed. Many students lost their part-time jobs due to the closure of local businesses [4,6].

Late adolescents are also vulnerable from a developmental perspective. Late adolescence is when cranial neural network development and atrophy, called pruning, occur simultaneously. The pruning of synapses starts in adolescence and continues until the late 20s [7]. Brain maturation, the rewiring process in the prefrontal lobe, is not complete until approximately 25 years of age [8]. Therefore, college students in late adolescence experience difficulties in emotion regulation because of the instability of the brain [9]. Petanjek et al. [7] revealed some changes in brain network connectivity related to aging from middle to late adolescence and sensitivity to stress response hormone regulation in the brain [10]. Therefore, mental health problems and school maladjustment may occur because of a lack of self-regulation [11]. When stress is prolonged or sustained as with COVID-19, the stress response is initiated in the actual brain system.

Despite great attention to self-regulation in previous research, there has been minimal research regarding a brain science approach in nursing intervention. The self-regulation mode is the ability to respond and control the intensity and frequency of verbal and physical activities during adolescence. If emotions are not properly controlled, internalization problems such as anxiety and anger arise, and externalization problems such as impulsivity and delinquency aggression can occur [11].

In particular, anxiety [12] and impulsivity [13] were found to be heightened in adolescence, and emotional distress was exacerbated through rumination [14]. However, meta-mood or self-regulation abilities might support effective emotion regulation [15]. Therefore, to measure the effects of Electroencephalogram (EEG) biofeedback training from the perspective of neurocognitive development in late adolescence, both emotional characteristics and strategic methods for helping emotion regulation were selected as dependent variables.

Uncertainty and fear of coronavirus infection can manifest as negative reactions such as infection anxiety, impulsivity, and anger [2]. High anxiety about the COVID-19 pandemic includes problematic responses that can cause impulsiveness or even anger that can eventually develop into self-destructive behavior in adolescents [13]. Impulsivity is usually defined as inappropriate and careless behavior without planning [16]. In a prolonged stress situation, people may take risks or make hasty decisions. They may also react haphazardly to internal and external stimuli without considering consequences. As a result, impulsivity can act as a factor in intrinsic or extrinsic problems. Anger also starts from resentment related to the inconveniences of daily life caused [17] by social distancing or social disconnection and can cause emotional-behavioral problems. Anxiety, impulsivity, and anger rumination [14] are trigger factors in late adolescence due to unstable brain function. Behavioral control of self-regulation requires great cognitive and executive functions in the prefrontal cortex [8]. Thus, nursing interventions related to brain science to control anxiety, impulsivity, and anger in late adolescence are necessary.

Meta-mood is the ability to check and adjust one's emotions on a reflective level through cognitive thinking [18]. Emotions related to experiences evoked by important events are multifaceted in terms of behavior and physiology. Controlling negative emotions in a COVID-19 situation requires clarity of emotion recognition in a meta-mood. Self-regulation ability is the process of controlling human functions and states by the self [14]. In general, two modes are discerned: adaptive goal-oriented self-regulation and maladaptive volitional intentional inhibition mode [19].

EEG biofeedback training, a self-regulation intervention based on brain science and also referred to as neurofeedback training, uses cranial nerve plasticity. Neurofeedback focuses on the central nervous system to improve neuroregulation and the stabilization of brain waves [20]. Neurofeedback training strengthens self-regulation ability by repeatedly training while seeing and hearing feedback in real-time using an operant conditioning paradigm. First studied by Berger [21], EEG was used to directly diagnose brain problems and detect brain dysfunction. The previous scientific literature shows that quantitative EEG (QEEG) is a very reliable and reproducible [22] approach when normative databases (Z-score) of the homeostasis of the human brain are used.

Self-regulation is a high-level executive process in the frontal lobe of the brain involving planning, inspection, monitoring, evaluation, and cognitive control as core components of emotional control [23]. Furthermore, there is a significant relationship between brain executive function and self-regulation [24]. In particular, ambiguity and uncertainty about new viral diseases, such as COVID-19, can trigger abnormal brain function in the cognitive, neurological system.

Since the 2000s, several previous studies have revealed the therapeutic effects of neurofeedback as an independent nursing intervention on fatigue and stress perception and immune response in nursing students [25], stress and depression [26], brain function in high school students [27], and autonomy control in patients with alcohol use disorder [28] in the domestic nursing field. To optimize the relief of emotional distress, such as anxiety about COVID-19 infection, impulsivity, anger rumination, meta-mood, and self-regulation ability during the COVID-19 pandemic, we analyzed the emotional characteristics of late adolescents, also referred to as digital natives because they have been exposed to the Internet since birth.

Therefore, in this study, we aimed to investigate the effects of EEG biofeedback brain computer interface (BCI) system-based interventions and to develop educational program content or standard practice guidelines for using EEG biofeedback training based on brain science in various clinical practices or nursing research areas as an independent nursing intervention in the COVID-19 pandemic situation.

1. Research question

In this study, we aimed to investigate the effects of EEG biofeedback training as an independent nursing intervention on emotion regulation and brain homeostasis in anxiety about COVID-19 infection, impulsivity, anger rumination, meta-mood, and self-regulation ability based on cognitive neuroscience.

2. Research hypotheses

1) Hypothesis 1: the experimental group that participated in EEG biofeedback training will have higher emotion regulation than the control group.

(1) The experimental group after intervention will have lower anxiety about COVID-19 infection than the control group.

(2) The experimental group after intervention will have lower impulsivity than the control group.

(3) The experimental group after intervention will have less anger rumination than the control group.

(4) The experimental group after intervention will have more meta-mood than the control group.

(5) The experimental group after intervention will have more self-regulation ability than the control group.

2) Hypothesis 2: the experimental group after intervention will have higher homeostasis brain waves than the pre-test.

METHODS

1. Design

This study used a quasi-experimental design that applied a non-equivalent control group pretest-posttest design to verify the effect on anxiety about COVID-19 infection, impulsivity, anger rumination, meta mood, self-regulation ability, and brain homeostasis by applying EEG biofeedback training to late adolescents.

2. Participants

Fifty-five late adolescents aged 19 to 24 years attending university and living in the cities of D and Y were selected. Participants were recruited by convenience sampling. The intervention of EEG biofeedback training was performed by monitoring EEG changes for 10 sessions with individual resting-state QEEG two times before and after 10 interventions. The sample size was calculated using the G*power 3.1.6 program. For the independent t-test, α .05, effect size 0.73, power .80, and minimum sample size were calculated for 24

 https://doi.org/10.4040/jkan.21155

people per group. Considering a dropout rate of approximately 20%, we selected 30 adolescents per group. The effect size of this study was selected based on the effect size of .73 for adolescents in a meta-analysis study [29]. The inclusion criteria were as follows: (1) agreement to participate and understand the purpose of the study, (2) no prior experience of participating in brain wave training before, (3) no head injuries or restrictions on physical movement, and (4) right-handedness. Candidates who took drugs related to EEG changes had a current or past history of any brain-related neurological diseases, and self-quarantine or confirmed positive COVID-19 virus cases were excluded due to the risk of emotional crisis such as the appearance of excessive emotional reactions. The national prevention guidelines for coronavirus were thoroughly followed, as not all study participants were vaccinated against COVID-19. Participants were divided into the experimental and control groups according to their decision. Total thirty participants were accepted in order of application as an experimental group. Three participants in the experimental group were dropped due to lack of attendance in the total 10 interventions, and two participants in the control group dropped out due to missing the post-test. The final dataset included the data from 27 participants in the experimental group and 28 people in the control group (Figure 1).

3. Researcher readiness

The researcher is a board-certified International Neurofeedback Training Clinical Specialist (Certificate No. #E5869) and an international QEEG diplomate as a clinical expert (Certificate No. #139) with certified skills of EEG measurement and analysis, application skills acquisition and mentoring courses required by the Biofeedback Certification International Alliance.

4. Electroencephalogram biofeedback nursing intervention

EEG produced by the brain's electrical activity and the functional state of the brain was measured in the superficial scalp. The electrical activity of the brain was displayed on a monitor in the form of audiovisual feedback. The study consisted of assessing a pre-test of emotional reactions, providing an intervention orientation, determining individual protocol based resting state EEG, implementing the nursing intervention, and reassessing QEEG and study variables to evaluate the effects of intervention (Figure 2).

An initial interview was conducted to describe the symptoms and health history. In the orientation, the study participants were recommended to limit the intake of caffeine,

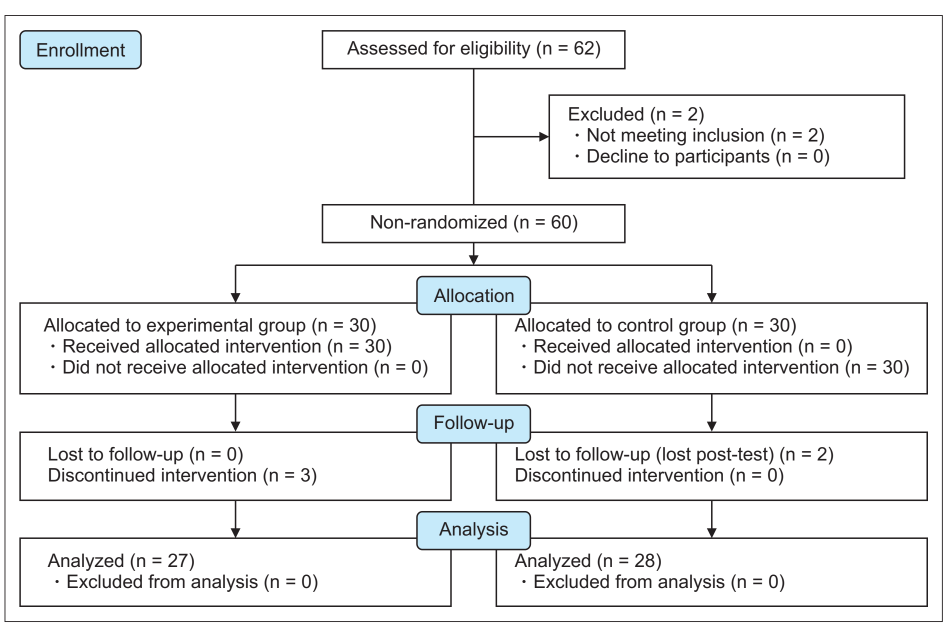
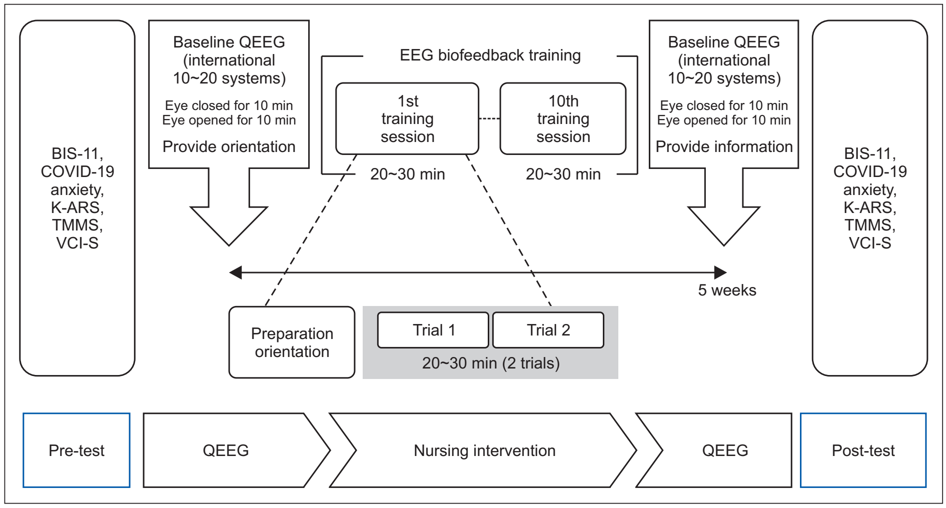


Figure 1. Flow diagram of study participants.



BIS-11 = The Barratt Impulsive Scale 11th version; EEG = Electroencephalography;
K-ARS = The Korean version of the Anger Rumination Scale; QEEG = Quantitative Electroencephalography;
TMMS = The Trait Meta-Mood Scale; VCI-S = The Volitional Components Inventory-Short version.

Figure 2. The research procedure.

over-the-counter medicines, and smoking on the day before intervention training, as well as to sleep adequately. Furthermore, they were recommended to avoid excessive exercise, overeating, or using a rinse, hair gel, mousse, or hairspray on the training day.

An individual's baseline QEEG before the intervention was measured to provide tailored individual interventions. We chose one of the two protocols with a three-band used protocol: protocol 1 rewarded sensory-motor rhythm (SMR) and inhibited theta and high beta in the Cz region for attention and emotion regulation if low SMR, high theta or high beta waves were observed in QEEG. Protocol 2 rewarded alpha and inhibited theta and high beta in the Pz region for relaxation and emotion regulation if alpha waves were high in the frontal lobe or low in the occipital lobe, and high theta or high beta were shown in QEEG [30]. Each neurofeedback training session consisted of two games about enhancing the homeostasis of EEG function that lasted 10~15 minutes each for 20~30 minutes a day; repetitive intervention was provided in 10 sessions for five weeks. In all 10 training sessions, the Procomp2 system with Biograph version 2.1 program (Thought Technology Ltd., Montreal, QC, Canada) were used to enhance alpha (8~12 Hz) or SMR (13~15 Hz) and inhibit theta (4~7 Hz) and high beta (25~30 Hz) waves [31]. The changing values of the EEG were measured in real time.

Neurofeedback training was administered while the subjects sat in a comfortable chair. The study participants faced a computer monitor approximately 50~60 cm away. During individual interventions, guidelines on the prevention of COVID-19 (i.e., ventilation, disinfection, wearing masks, and checking temperature) were thoroughly followed. While the control group have not received intervention.

5. Measures

1) Baseline quantitative electroencephalography

QEEG was performed before and at the end of the sessions to determine the individual strategy of intervention directions and the effects of neurofeedback. Resting QEEG was used to measure baseline brain function. The International Federation of Clinical Neurophysiology recommends pre-measurement of QEEG using the international 10~20 system [32] with an electrode cap (Electro-Cap International Inc., Eaton, OH, USA). The QEEG was amplified, filtered, and digitized using fast Fourier transform (FFT) as individual frequencies such as a prism and decoding the raw waveform. Basic resting EEG was recorded for 10 minutes with closed eyes and 10 minutes with opened eyes using 19 electrode locations on the scalp: FP1, FP2, F3, Fz, F4, F7, F8, C3, Cz, C4, T3, T4, T5, T6, P3, Pz, P4, O1, and O2 (Applied Mitsar Co. Ltd., Saint Petersburg, Russia) with two reference electrodes on the left and right ears. The QEEG was extracted using the Neuroguide software (Applied Neuroscience) program by using the Z-score absolute power value and absolute power for selecting the target EEG bands: delta (0~3 Hz), theta (4~7 Hz), alpha (8~12 Hz), SMR (13~15 Hz), and beta (16~32 Hz) bands.

2) Anxiety about COVID-19 infection

The original Swine Flu Anxiety Inventory tool developed by Wheaton et al. [17], consisting of nine items, was used after obtaining permission. Park et al. [5] revised the Korean version of the COVID-19 pandemic. After two bilingual experts performed reverse translation, six expert groups of nurses reviewed the content validity and used it for infection anxiety about COVID-19 without any modification from swine flu. The scale items were rated on a 5-point scale, with higher scores indicating higher anxiety. The reliability of Cronbach's α was .85 in Wheaton et al. [17], and .76 in Park et al. [5], and .73 in the present study.

3) Impulsivity

The impulsivity scale developed by Patton et al. [33] is a screening tool with three factors: motor, cognitive, and non-planning. Heo et al. [16] revised the Korean version of the Barratt Impulsive Scale 11th version (K-BIS 11). The scale was used after obtaining permission from the tool developers. A total of 30 items were used, with 8 questions on cognitive impulsivity, 11 questions on motor impulsivity, and 11 questions on unplanned impulsivity. The questions were rated on a 4-point scale, with higher scores indicating higher impulsivity. The test-retest reliability in the revised tool was .85~.95. The Cronbach's α of cognitive, motor impulsivity and unplanned impulsivity were .70, .58, and .61, respectively, in Heo et al.'s study [16]. In the present study, Cronbach's α was .88, and those of the subgroups were .75, .74, and .72.

4) Anger rumination

The Anger Rumination Scale (ARS) was developed by Sukhodolsky et al. [34] to measure the tendency focused on angry moods. Lee and Cho [35] revised the Korean version of the Anger Rumination Scale (K-ARS) from a validation study using factor analysis and yielded three subgroups: eight angry afterthoughts, three understandings of causes, and five thoughts of revenge. The scale was used after obtaining the permission. A total of 16 items were rated on a 4-point scale ranging from 1 (never) to 4 (almost always). The total Cronbach's α in Sukhodolsky et al.'s study [34] was .93. Cronbach's α values, as reported by Lee and Cho [35], were angry afterthoughts .90, understanding of causes .76, and thoughts of revenge .75. In the present study, Cronbach's α values of the subgroup were .92, .83, and .74, and the total Cronbach's α was .92.

5) Meta-mood

The Trait Meta-Mood Scale (TMMS) was developed by Salovey et al. [15] to measure the ability to reflect and manage emotions. Lee and Lee [36] revised the Korean TMMS based on a university sample. The scale was used after obtaining permission from the developers. The questionnaire consists of 21 items to assess three factors with 11 items on the clarity of one's mood, five items on attention to one's mood, and five items on mood repair. A 5-point scale ranging from 1 (almost never) to 5 (almost always) was used, with higher scores indicating higher meta-mood. The original instrument's [15] Cronbach's α was clear in discrimination of feelings .84, attention to feelings .74, and mood repair .72. The Cronbach's α in Lee and Lee [36] were .84, .74, .72, and .87, .90, and .81 respectively. Cronbach's α for the total instrument in the present study was .87.

6) Self-regulation ability

The Self-Regulatory Ability Scale developed by Kuhl and Fuhrmann [37] was used after obtaining permission from the developers. Yoon [38] modified and revised the Volitional Components Inventory-short version (VCI-S) measurement into a Korean version. The questions were 21 items, 10 questions on self-regulation mode, and 11 questions on volitional inhibition mode. The questionnaire was rated on a 4-point scale ranging from 1 (never) to 4 (almost always), with higher scores indicating higher self-regulation ability. Items corresponding to the volitional inhibition mode were reverse-scored: the higher the score of the volitional inhibition modality, the lower the repressive self-regulation, which means that maladaptive self-regulation does not occur for goal performance. Cronbach's α values were .76 and .75 for self-regulation mode and volitional inhibition mode, respectively, as reported by Yoon [38]. The reliabilities in the present study were .77 and .76, respectively.

6. Data collection and process

In the experimental group, the participants were reminded of the specific purpose and procedure of the EEG biofeedback training intervention during the initial visit with a 1:1 interview, and a schedule was planned for each individual. A total of 27 participants completed the training program. To maintain the consistency of data collection, we collected the same questionnaire before and after the intervention over the same period for five weeks. Additionally, to control exogenous variables, neither of the two groups participated in any other intervention while participating in this program.

The participants were reassured that their anonymity would be guaranteed, that the data would not be used for purposes other than research, and that all personal information would be kept confidential. Furthermore, participants were informed that they could withdraw from the study at any time. A detailed explanation of the results of the EEG measurements of each individual was provided. To minimize the dropout of the participants in the experimental group, compensation of about 50,000 won as a transportation fee for intervention was paid after 10 training sessions; 10,000 won were offered for the online survey.

7. Data analysis

The collected data were analyzed using SAS 9.3 (SAS Institute, Cary, NC, USA). The general characteristics are described in terms of number and percentage. A normality test was performed using the Shapiro-Wilk test. To statistically compensate for the bias between the experimental and control groups, a homogeneity test was performed on general characteristics and variables. These were compared using a t-test and Wilcoxon rank sum test for continuous variables and the χ^2-test and Fisher's exact test for categorical variables. For hypothesis testing, t-test and paired t-test of parametric analysis, as well as Wilcoxon rank sum test and Wilcoxon signed-rank test of nonparametric analysis were used to satisfy normality. The frequency series power spectrum analysis method through FFT was used for EEG data analysis. QEEG was analyzed so that the normalized absolute power value did not deviate from the confidence interval (Mean ± 1.65) and converged to the normal range using only data of over 95% split-half reliability and 90% test-retest reliability.

8. Ethical considerations

The data were collected individually from 15 April to 20 July 2021 in a study room or a quiet room in the school. This study was approved by the Institutional Review Board of Kyungpook National University (No-2021-0054) to minimize ethical issues and follow the research protocol. The purpose of the study was notified in an announcement on a blog, and all participants provided informed consent for participation in the online survey.

RESULTS

1. Homogeneity test of the general characteristics and study variables

No statistically significant differences were observed between the two groups with respect to the general characteristics and study variables. In terms of general characteristics, man in the experimental and control groups accounted for 18.5% and 39.3%, respectively, while the proportions of woman in the experimental and control groups were 81.5% and 60.7%, respectively; no significant difference between the two groups was observed (χ^2 = 2.87, p = .090). Similarly, there was no difference between the two groups in other general characteristics (p > .05). Additionally, no significant difference between the two groups was found in anxiety about COVID-19 infection, impulsivity, anger rumination,

 https://doi.org/10.4040/jkan.21155

Table 1. Homogeneity Test of General Characteristics and Study Variables between Groups (*N* = 55)

Variables	Total	Exp. (n = 27)	Cont. (n = 28)	χ^2 or t/W†	*p*
	n (%) or M ± SD	n (%) or M ± SD	n (%) or M ± SD		
Gender				2.87	.090
Men	16 (29.1)	5 (18.5)	11 (39.3)		
Women	39 (70.9)	22 (81.5)	17 (60.7)		
Grade				3.58	.386
Freshman	3 (5.5)	0 (0.0)	3 (10.7)		
Sophomore	8 (14.5)	5 (18.5)	3 (10.7)		
Junior	19 (34.5)	10 (37.1)	9 (32.2)		
Senior	25 (45.5)	12 (44.4)	13 (46.4)		
Resident type				0.16	.924
Home	25 (45.5)	12 (44.4)	13 (46.4)		
Live alone	17 (30.9)	9 (33.3)	8 (28.6)		
Dormitory	13 (23.6)	6 (22.3)	7 (25.0)		
Family relationship				1.93	.358
Satisfaction	41 (74.5)	18 (66.7)	23 (82.2)		
Medium	12 (21.9)	8 (29.6)	4 (14.2)		
Dissatisfaction	2 (3.6)	1 (3.7)	1 (3.6)		
Numbers of close friends				1.74	.187
< 7	18 (32.7)	7 (25.9)	11 (39.3)		
≥ 7	37 (67.3)	20 (74.1)	17 (60.7)		
School life satisfaction				4.17	.179
High	26 (47.3)	14 (51.9)	12 (42.9)		
Medium	25 (45.5)	13 (48.1)	12 (42.9)		
Low	4 (7.2)	0 (0.0)	4 (14.2)		
Academic stress				1.03	.596
High	21 (38.2)	12 (44.4)	9 (32.2)		
Medium	31 (56.3)	14 (51.9)	17 (60.7)		
Low	3 (5.5)	1 (3.7)	2 (7.1)		
Stress of taking a job				2.15	.340
High	22 (40.0)	13 (48.1)	9 (32.2)		
Medium	26 (47.3)	12 (44.4)	14 (50.0)		
Low	7 (12.7)	2 (7.4)	5 (17.8)		
Anxiety about COVID-19 infection	3.65 ± 0.58	3.67 ± 0.57	3.64 ± 0.60	− 0.80	.840
Impulsivity	2.17 ± 0.39	2.16 ± 0.39	2.19 ± 0.40	0.33	.746
Cognitive impulsivity	2.23 ± 0.50	2.21 ± 0.53	2.24 ± 0.49	0.17	.864
Motor impulsivity	2.08 ± 0.46	2.07 ± 0.49	2.09 ± 0.44	746.50†	.873
Unplanned impulsivity	2.23 ± 0.43	2.20 ± 0.39	2.26 ± 0.47	724.00†	.588
Anger rumination	2.39 ± 0.62	2.40 ± 0.61	2.39 ± 0.65	− 0.06	.955
Angry afterthoughts	2.50 ± 0.77	2.50 ± 0.76	2.49 ± 0.79	− 0.09	.932
Understanding of causes	2.80 ± 0.80	2.90 ± 0.85	2.70 ± 0.76	− 0.92	.363
Thoughts of revenge	1.99 ± 0.63	1.93 ± 0.59	2.04 ± 0.67	0.68	.497
Meta-mood	3.54 ± 0.55	3.51 ± 0.53	3.57 ± 0.57	0.36	.722
Clarity of one's mood	3.68 ± 0.68	3.63 ± 0.72	3.72 ± 0.65	747.00†	.879
Attention to one's mood	3.69 ± 0.88	3.90 ± 0.81	3.50 ± 0.91	856.00†	.091
Mood repair	3.09 ± 0.86	2.89 ± 0.83	3.29 ± 0.85	1.78	.081
Self-regulation ability	2.54 ± 0.37	2.48 ± 0.39	2.60 ± 0.34	1.20	.234
Self-regulation mode	2.62 ± 0.40	2.52 ± 0.37	2.71 ± 0.42	1.81	.076
Volitional inhibition mode	2.47 ± 0.49	2.45 ± 0.53	2.50 ± 0.46	0.39	.697

Cont. = Control group; Exp. = Experimental group; M = Mean; SD = Standard deviation.
†Wilcoxon rank sum test.

meta-mood, and self-regulation ability before the experimental intervention (p>.05) (Table 1).

2. Effects of electroencephalogram biofeedback training on emotion regulation

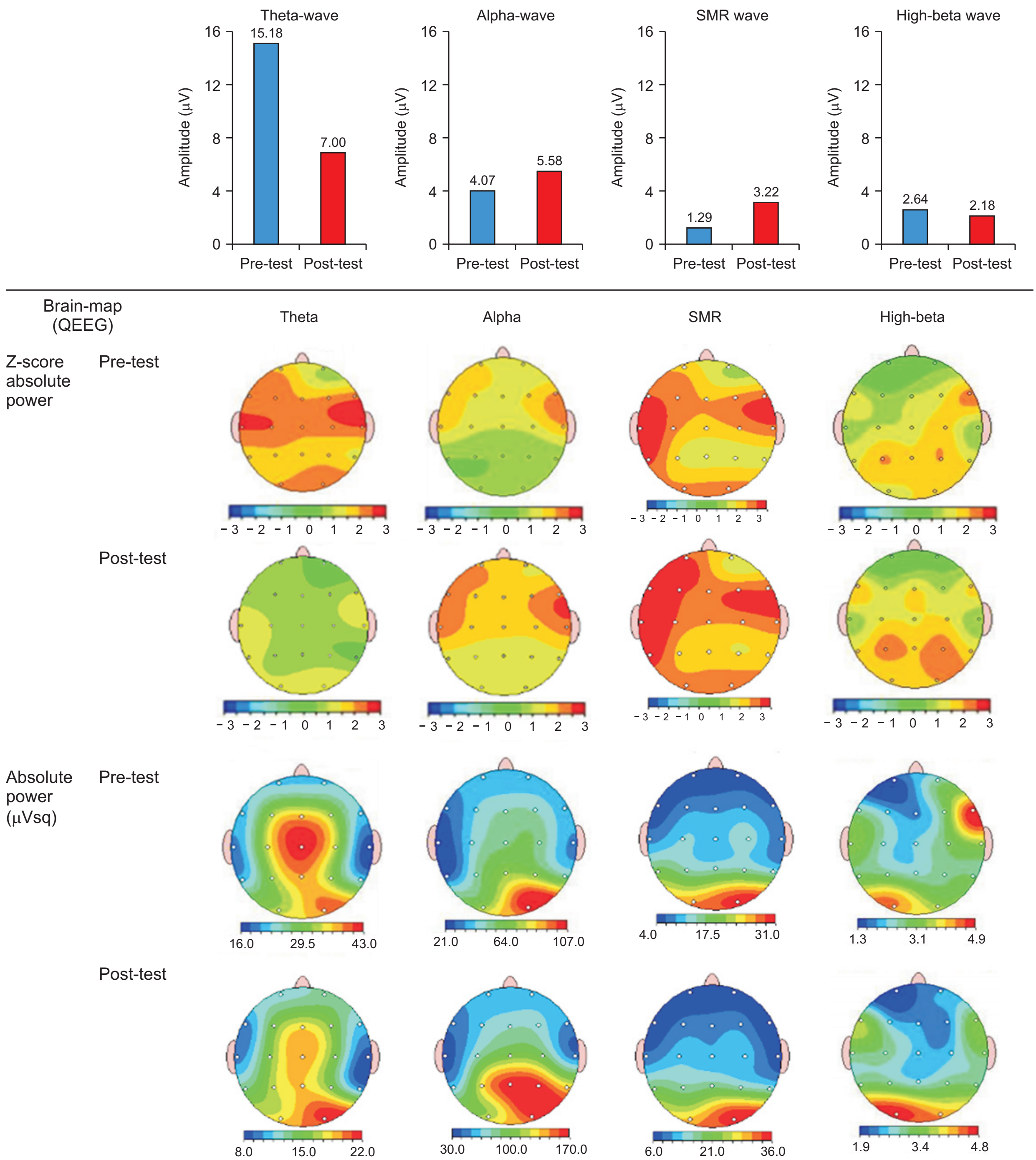
Hypothesis 1 was partially verified. The sub-hypothesis about the anxiety about COVID-19 infection and self-regulation ability showed significant differences between the two groups. There were significant differences in anxiety about COVID-19 infection between the two groups (W = 585.50, p = .002). Specifically, the experimental group were significantly decreased at the pre-post score after the intervention (S = −108.50, p = .007), but the control group was significantly increased at the pre-post score (S = 88.00, p = .032). In both impulsivity and anger rumination, no significant differences were found between the two groups (p>.05), even though both cognitive impulsivity (t = −2.36, p = .026) and angry afterthoughts (t = −2.15, p = .041) in the experimen-

Table 2. Effects of EEG Biofeedback Training between Groups (*N* = 55)

Variable	Group	Pre-test	Post-test	t/S†	*p*	Diff	t/W††	*p*
		M ± SD	M ± SD			M ± SD		
Anxiety about COVID-19 infection	Exp.	3.67 ± 0.57	3.13 ± 1.02	− 108.50†	.007	− 0.54 ± 0.86	585.50††	.002
	Cont.	3.64 ± 0.60	3.89 ± 0.43	88.00†	.032	0.25 ± 0.51		
Impulsivity	Exp.	2.16 ± 0.39	2.12 ± 0.36	− 0.85	.403	− 0.03 ± 0.19	739.00††	.775
	Cont.	2.19 ± 0.40	2.19 ± 0.34	− 0.05	.958	0.00 ± 0.23		
Cognitive impulsivity	Exp.	2.21 ± 0.53	2.08 ± 0.51	− 2.36	.026	− 0.13 ± 0.30	0.37	.710
	Cont.	2.24 ± 0.49	2.13 ± 0.46	− 1.66	.109	− 0.10 ± 0.33		
Motor impulsivity	Exp.	2.07 ± 0.49	2.05 ± 0.40	10.50†	.740	− 0.02 ± 0.25	700.00††	.344
	Cont.	2.09 ± 0.44	2.13 ± 0.35	38.00†	.284	0.04 ± 0.29		
Unplanned impulsivity	Exp.	2.20 ± 0.39	2.23 ± 0.41	28.50†	.397	0.03 ± 0.26	781.50††	.667
	Cont.	2.26 ± 0.47	2.28 ± 0.44	10.00†	.781	0.03 ± 0.30		
Anger rumination	Exp.	2.40 ± 0.61	2.28 ± 0.58	− 1.69	.103	− 0.12 ± 0.37	696.00††	.311
	Cont.	2.39 ± 0.65	2.29 ± 0.60	− 1.54	.135	− 0.09 ± 0.31		
Angry afterthoughts	Exp.	2.50 ± 0.76	2.31 ± 0.71	− 2.15	.041	− 0.19 ± 0.46	0.57	.574
	Cont.	2.49 ± 0.79	2.36 ± 0.74	− 1.69	.102	− 0.13 ± 0.39		
Understanding of causes	Exp.	2.90 ± 0.85	2.88 ± 0.69	− 0.16	.876	− 0.02 ± 0.81	766.00††	.863
	Cont.	2.70 ± 0.76	2.60 ± 0.70	− 0.86	.399	− 0.11 ± 0.66		
Thoughts of revenge	Exp.	1.93 ± 0.59	1.86 ± 0.69	− 29.50†	.242	− 0.07 ± 0.38	0.27	.790
	Cont.	2.04 ± 0.67	2.01 ± 0.57	− 6.00†	.840	− 0.04 ± 0.47		
Meta-mood	Exp.	3.51 ± 0.53	3.67 ± 0.58	2.54	.017	0.16 ± 0.32	− 1.50	.140
	Cont.	3.57 ± 0.57	3.59 ± 0.52	0.27	.789	0.02 ± 0.37		
Clarity of one's mood	Exp.	3.63 ± 0.72	3.78 ± 0.71	78.00†	.032	0.15 ± 0.45	795.00††	.510
	Cont.	3.72 ± 0.65	3.84 ± 0.62	57.50†	.194	0.12 ± 0.51		
Attention of one's mood	Exp.	3.90 ± 0.81	4.04 ± 0.61	33.00†	.385	0.14 ± 0.56	792.50††	.538
	Cont.	3.50 ± 0.91	3.44 ± 0.96	-5.50†	.871	− 0.06 ± 0.87		
Mood repair	Exp.	2.89 ± 0.83	3.08 ± 0.99	1.32	.198	0.19 ± 0.76	889.50††	.024
	Cont.	3.29 ± 0.85	3.17 ± 0.86	− 1.16	.256	− 0.12 ± 0.55		
Self-regulation ability	Exp.	2.48 ± 0.39	2.58 ± 0.44	2.15	.041	0.10 ± 0.25	− 5.02	< .001
	Cont.	2.60 ± 0.34	2.38 ± 0.29	− 5.08	< .001	− 0.22 ± 0.23		
Self-regulation mode	Exp.	2.52 ± 0.37	2.71 ± 0.49	2.58	.016	0.19 ± 0.38	− 4.74	< .001
	Cont.	2.71 ± 0.42	2.40 ± 0.36	− 4.11	< .001	− 0.31 ± 0.40		
Volitional inhibition mode	Exp.	2.45 ± 0.53	2.47 ± 0.51	0.54	.591	0.02 ± 0.22	− 2.61	.012
	Cont.	2.50 ± 0.46	2.36 ± 0.45	− 3.14	.004	− 0.14 ± 0.23		

Cont. = Control group; EEG = Electroencephalography; Exp. = Experimental group; M = Mean; SD = Standard deviation.
†Wilcoxon signed-rank test; ††Wilcoxon rank sum test.

Amplitude of brain wave	Theta	Alpha	SMR	High-beta
Pre-test	15.18 ± 9.41	4.07 ± 3.93	1.29 ± 1.06	2.64 ± 0.99
Post-test	7.00 ± 4.90	5.58 ± 5.52	3.22 ± 2.33	2.18 ± 1.01
t/S†	− 166.00†	68.00†	177.00†	− 1.91
p	< .001	.103	< .001	.067



QEEG = Quantitative Electroencephalography; SMR = Sensory Motor Rhythm.
†Wilcoxon signed-rank test.

Figure 3. Difference of brain wave and QEEG between pre-test and post-test in the experimental group.

tal group were significantly decreased at the pre-score and post-score in sub-groups. There were significant differences in mood repair of meta-mood between the two groups (W = 889.50, p = .024). However, no significant differences were found at the pre-score and post-score in the two groups (p > .05).

There were significant differences in self-regulation ability between the two groups (t = −5.02, p < .001). Specifically, the experimental group significantly increased after the intervention (t = 2.15, p = .041), but the control group showed a significant decrease in pre-and post-intervention scores (t = −5.08, p < .001). In the self-regulation mode, there were significant differences between the two groups (t = −4.74, p < .001). The experimental group significantly increased after the intervention (t = 2.58, p = .016), but the control group showed a significant decrease in pre-and post-scores (t = −4.11, p < .001). Even though the experimental groups in volitional inhibition mode were not significant, the control group showed a significant decrease in pre-and post-scores (t = −3.14, p = .004). Therefore, there were significant differences between the two groups (t = −2.61, p = .012) (Table 2).

3. Effects of electroencephalogram biofeedback training on brain wave homeostasis

Hypothesis 2 of this study was partially verified because the homeostasis of theta and SMR brain waves only improved significantly. The mean amplitude of theta waves in the pre-score and post-score of the experimental group significantly decreased (S = −166.00, p < .001). The mean of amplitude of the SMR waves in the pre-score and post-score of the experimental group significantly increased (S = 177.00, p < .001). Although alpha waves increased, while high beta waves slightly decreased after the neurofeedback training intervention, none of these changes were statistically significant (p > .05). Sample examples of a brain map of the effects changed from pre-test to post-test QEEG analysis using the Z-score absolute power and absolute power of brain waves are shown in Figure 3.

DISCUSSION

In this study, we investigated whether EEG biofeedback training is effective in emotion regulation for late adolescents as an independent nursing intervention in the COVID-19 pandemic. EEG biofeedback training intervention is the basis of the cognitive neuroscientific approach to explore brain function to reveal the essence of human emotion regulation.

The first hypothesis was partially supported. The results revealed that neurofeedback training is an effective tool for emotion regulation. After neurofeedback training, the self-regulation ability of the experimental group increased. This result was consistent with the findings reported by Choi and Park [31] and Barrows and Jacobs [39], who found a significant positive change in self-regulation in late adolescence. Self-regulation ability can be defined as the dynamic process of regulating and maintaining motivation, cognition, and emotion to achieve one's desired goals [40]. In this study, both self-regulation and volitional inhibition modes showed significant effects after the intervention. Self-regulation ability can be seen as lowering the stress level and motivating and organizing adaptive behavior [41]. Kuhl and Fuhrmann [37] believed that thinking and planning in intentional memory occurs in the left lobe of the brain. In contrast, intentional memory controls goal maintenance and intuitive conventions in the right lobe of the brain to support positive emotions. Therefore, EEG biofeedback training can help control adolescents' negative emotions elicited by the COVID-19 pandemic. The results confirmed that EEG biofeedback training could be an appropriate procedure for emotion regulation.

The pre-test scores of anxiety about COVID-19 infection were 3.67 in the experimental group and 3.64 in the control group. These findings are consistent with the results previously reported by Park et al. [5], who showed that university students' anxiety was 3.70. The total sum of anxiety was 33.3, and it seemed that coronavirus-related anxiety was significantly higher than that of Ebola infection (13.92) and swine flu (22.87). This means that late adolescents have high anxiety about COVID-19 infection in their daily lives. Similar to several clinical reports on the effectiveness of neurofeedback training for anxiety disorder [42,43], anxiety was found to significantly decrease from 3.67 to 3.13 after the intervention. Anxiety is caused by ambiguity or uncertainty about the present situation or future events. However, in the present study, we provided brain-based biological interventions such as learned relaxation methods to reduce anxiety and change their biomarkers using biofeedback with repetitive training that can enhance monitoring, concentration, and self-regulation. Therefore, neurofeedback training that combines methods of both mind-body medical intervention and nursing education intervention will have the advantage of reducing anxiety compared to providing accurate information only.

Furthermore, we found that cognitive impulsivity decreased significantly in the experimental group. These results contradicts the finding of Joo and Son's [44] that game-addicted late adolescents have significantly reduced impulsivity. The level of attention and arousal increased by enhancing the SMR waves and decreasing theta. Although a previous study revealed that impulsivity gradually decreased [44], in our results, no significant differences between the two groups were observed after providing EEG biofeedback training. Therefore, it is recommended to increase the intervention period and sessions to 20 or more during the COVID-19 pandemic situation.

Angry afterthoughts significantly decreased after neurofeedback training only. Anger is a universal human emotion that usually arises from an overload of stress, such as in the context of the recent COVID-19 pandemic. Moreover, frustration and dissatisfaction due to social distancing or isolation in the COVID-19 situation may cause anger that starts from resentment due to school closure, suspension of school schedules, and changes in personal daily life routines, which were not the students' faults. Furthermore, anger provides important energy for survival by eliciting the physiological motivation to cope with danger and protect ourselves from our environment and situations [45]. With additional nursing education on anger management, nurses can help adolescents learn to use functional anger, rather than dysfunctional anger.

The clarity of emotion in meta-mood showed a significant difference after neurofeedback training in the experimental group only. Emotions are multifaceted phenomena related to experience, behavior, and physiological changes. Meta-mood is the ability to check and adjust one's feelings or emotions on a reflective level through cognitive thinking [18]. The clarity of emotional recognition is the basic ability to understand one's own emotional state [18]. Control of negative emotions, such as anxiety and anger, in the COVID-19 situation, requires clarity of emotion recognition. A previous study on adolescents by Lee [46] revealed that adolescents who recognize emotions tend to use more adaptive emotion regulation. Furthermore, people with negative emotions have difficulty maintaining self-regulation in stressful situations and exhibit maladaptive behavior. For instance, Anttila et al. [47] noted that less preventive behavior was observed in individuals with a high level of negative emotions. In stressful situations such as COVID-19, the greater the difficulty in emotion regulation, the more inappropriate the coping strategies that can follow.

Only mood repair of the meta-mood showed a significant difference between the two groups after neurofeedback training. If people can better understand and express their feelings, they can better adjust their emotions through cognitive thinking in adaptive or functional ways [36]. The advantage of this study was that we provided individual protocols to increase the homeostasis of brain function using strategies regarding the participants' attention to auditory and visual feedback during the intervention. Interest and motivation were generated through computer games with repetitive training sessions. The individuals in the experimental group used self-learning and self-evaluated their improvement with a computer monitor during the training process. The goal of training interventions was to train the study participants to normalize spectral distribution by using the Z-score of normal brain function since training one area of the brain can affect a wide area of brain functions.

The second hypothesis was partially supported. Electrodes placed on the midline sagittal plane of the skull (Cz and Pz) and used mostly for measurement points showed good results. The Cz region refers to the midline central region of the head, where the sensory motor lobe is located, and Protocol 1 is used to enhance the SMR and reduce theta and high beta waves. The sensory-motor zone of the Cz region is a structural and functional center of the cortex with a higher density of primary system innervation, which has a greater influence, reduces artifacts during training, and can enhance SMR waves to enhance attention with relaxation. The results revealed that enhancing SMR to concentrate and recognize emotions can help develop proper coping mechanisms.

The location of Pz in the international 10~20 system is an important part of the parietal or occipital regions, and it is normal if the alpha waves are higher in the middle line posterior to the head than at the front [30]. An increased alpha wave was observed on the posterior midline scalp electrodes (Pz). Protocol 2 was used to enhance alpha and reduce theta and high-beta waves in the Pz region. The hyperactivity of alpha waves in the frontal lobe usually indicates depression or difficulty concentrating. This suggests that the frontal lobe is too relaxed and does not function properly. Although neurofeedback training usually has a significant improvement effect on reducing anxiety [48], Lipp and Cohen Kadosh [49] recommend using additional neurofeedback training with cognitive behavior therapy or other interventions. Therefore, combined effective intervention strategies are needed to develop interventions for late adolescents in the COVID-19 pandemic situation.

If more information is repeatedly provided every day because of the continuously changing prevention protocol for COVID-19, it may further increase anxiety [3]. EEG biofeedback is a suitable way to learn how to control anxiety and emotion regulation easily. Computer games based on brain science are very easy to concentrate on and can be used to monitor the changes in physical responses from negative emotion reactions in EEG biofeedback training and to check the improvement of brain function, which changes little by little every session through repeated training with rewards and suppression of biofeedback training.

Despite the observed positive effects of the tested neurofeedback training, the present study has several limitations. First, convenience sampling was used due to the regular collection of individual brain waves by monitoring each time during 10 sessions. In future research, we strongly recommend a controlled study with larger samples and additional sessions on a regular basis.

Despite these limitations, this study contributes to the available research by pre-evaluating an individual's resting basis of state QEEG before intervention to find individualized protocol strategies with a three-band protocol by inhibiting and rewarding brain waves. This training is a type of cognitive-behavioral therapy that uses the operant conditioning principle [50]. In other words, it seems that relaxation and concentration for self-regulation, which gives and receives feedback in real-time brain function, helps solve emotional distress from the COVID-19 pandemic.

Furthermore, our results are meaningful because they confirm the effects of EEG biofeedback intervention on various emotional problems in COVID-19 for psychiatric mental health nurses and nurse practitioners. The intervention we tested was noninvasive and non-pharmacological. Furthermore, by combining neurofeedback and other psychological nursing interventions, long-term intervention should be recommended in late adolescents who need to regulate emotional distress during the COVID-19 pandemic situation.

CONCLUSION

In this study, we used a brain science approach as an independent nursing intervention for late adolescents facing the COVID-19 pandemic to evaluate the effects of a neurofeedback-driven QEEG-based computer game. Each study participant not only performed tasks related to each game but also kept their brain waves at the optimal level while receiving visual and auditory feedback on their own brain functions. The results confirmed that emotional problems could be solved by EEG biofeedback training, suggesting that neurofeedback training can be used by nurses or nurse practitioners as a mental health intervention. Additionally, this intervention can be effective for clinical nurses suffering from fatigue elicited by the prolonged COVID-19 situation. Our results demonstrate the ability of a neurocognitive approach to improve emotion regulation in late adolescents.

CONFLICTS OF INTEREST

The authors declared no conflict of interest.

ACKNOWLEDGEMENTS

None.

FUNDING

This study was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. NRF-2019R1A2C108947112).

DATA SHARING STATEMENT

Please contact the corresponding author for data availability.

AUTHOR CONTRIBUTIONS

Conceptualization or/and Methodology: Park W.
Data curation or/and Analysis: Cho M.
Funding acquisition: Park W.
Investigation: Park S.
Project administration or/and Supervision: Park W.
Resources or/and Software: Cho M.
Validation: Cho M.
Visualization: Park S.
Writing original draft or/and Review & Editing: Park W & Park S.

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