

Psychophysiological and Psychological Responses of Teenage Students Conducting Computer Programming Activities Combined with Horticultural Activities

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KEYWORDS. brain waves, coding, elementary and middle school students, horticultural activities

ABSTRACT. This study investigated whether coding (computer programming) and horticultural activities alone and combined have psychophysiological and psychological effects. Compulsory computer programming has been required in elementary schools in South Korea since 2018. A total of 34 participants, who were students between the ages of 11 and 16 years were involved in the study. Participants undertook the following activities in random order: connecting components, coding, horticultural activities, and combining coding and horticultural activities (run program, horticultural activities, and coding modifications). Brain waves were measured during the activity, and a subjective self-report evaluation was conducted at the end of each activity. In a spectral edge frequency of 50% of the alpha spectrum band, which indicates a comfortable, stable, and relaxed state, there was a significant difference in the left prefrontal pole when participants performed a combination of coding and horticultural activities ($P < 0.001$). In addition, there were significant differences in the coding activities based on horticultural activities ($P < 0.05$, $P < 0.001$), with a relatively low beta, indicating attention and alertness; relative mid beta, indicating active awareness; ratio of SMR to theta, indicating focused attention; and the ratio of mid beta to theta, indicating concentrated focus. It is judged that activities involving plant engagement can contribute to comfort, stability, focused attention, and positive effects in response to active stimuli. As a result of a subjective evaluation, it was found that horticultural activities had a positive effect on participants' emotions ($P < 0.01$). This study demonstrates that horticulture-based coding activities have a positive impact on physiological relaxation and cognitive enhancement, and are also associated with subjectively reported positive emotions.

With the advancements in information and communication technology, the fourth industrial revolution was accelerated, emphasizing the significance of software competence. As a result, the importance of software education was highlighted. Software education encompasses various concepts such as

education, computer programming education (i.e., coding), and computational thinking (Lee 2018). Computational thinking is considered an essential element in child education (Wing 2008), and software education has been implemented actively since elementary school in countries such as the United States and the United Kingdom (Barr and Stephenson 2011; Bers et al. 2014; Grover and Pea 2013; Lye and Koh 2014). Since 2014, the United States and the United Kingdom have mandated software education as a compulsory subject in elementary school, and Japan has made software education mandatory in elementary school, beginning in 2020. France integrated software education into the regular curriculum in 2016. In South Korea, the Ministry of Education (2022) issued *Software Education Operation Guidelines* in the revised curriculum of 2015. Since 2018 in

South Korea, practical courses in elementary school and information courses in middle school have provided more than 17 h of software education, and, beginning in 2025, software education will become mandatory in both elementary and middle schools.

Horticultural activities are effective in restoring and enhancing physical, mental, and social well-being (Son et al. 2006). Natural environments provide more protection from the impacts of environmental stressors and offer physiological, emotional, and attentional restoration compared with urban environments (Staats et al. 2003). Exposure to nature is associated with numerous benefits, including improved attention, stress reduction, mood enhancement, decreased risk of mental disorders, and even increased empathy and cooperation (Meidenbauer et al. 2020). To escape the burdens of modern society, individuals seek natural environments for mental and physical rejuvenation (Cohen 1978; Kaplan 1995; Lee and Hyun 2003; Ulrich et al. 1991).

In horticultural activities, plants have a positive effect on individuals. Even in flower-arranging activities, it was shown that blood pressure decreases and alpha brain wave activity increases (Lee et al. 2015; Tao et al. 2020). Indoor horticultural activities among elementary school students have been shown to enhance concentration (Lee et al. 2013), and visual stimulation from green plants has a positive effect on concentration and emotional stability in elementary school students (Oh et al. 2019).

On the other hand, there are both physical and psychological disadvantages involved with the use of computers. Prolonged repetitive tasks performed using computers are associated with an increased prevalence of musculoskeletal symptoms in the neck, shoulders, hands, and wrists (Jensen et al. 2002a, 2002b). In addition, computer activities can lead to a decrease in parasympathetic nervous system activity, which can result in tension and stress (Garde et al. 2002; Hjortskov et al. 2004). A study involving coding activities based on horticulture showed an increase in sustained attention as indicated by relative beta (RB) among adults (Jeong and Park 2022). Although coding and horticultural activities have, individually, demonstrated positive effects, there has been

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The datasets generated for this study are available on request to the corresponding author.

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limited research on the physiological effects of combining coding and horticulture activities for students between the ages of 11 and 16 years. Therefore, this study combined horticulture, coding, and a fusion of horticulture and coding activities to measure the brain waves generated by participants during the activities to understand their physiological responses.

Materials and methods

PARTICIPANTS. This study targeted students age 11 to 16 years and recruitment was conducted in schools, academies, and online communities in Seoul, South Korea. Interested participants were provided with explanations of the study and voluntary consent was obtained from both the participants and their parents. This research was conducted with the approval of the Konkuk University Institutional Review Board (Project No. 7001355-202203-HR-532).

EXPERIMENTAL CONDITIONS. The study was conducted in a 2.2- × 1.9-m space within the experimental area of Konkuk University (Konkuk University, Seoul, South Korea). The environmental factors within the space were maintained consistently, with an average temperature of 24.9 ± 2.8°C and an average humidity of 57.1 ± 13.2%. To minimize the influence of external stimuli during the experiment, ivory-colored curtains were installed on the front and sides of the experimental space, and a white sheet was placed on the desk. Chairs with adjustable heights were placed in front of the center of the desk to accommodate participants of varying heights. All the activities were conducted by one person at a time.

ACTIVITIES. The process of creating a smart plant cultivation pot was divided into four distinct activities: connecting components, coding, horticultural activities, and combined coding and horticultural activity. Among these four activities, horticultural activities and combined coding and horticultural activity involve activities with plants, whereas the others were activities without plants. The order of the activities was not fixed; the activities were carried out in a random order. Arduino (Arduino; Arduino S.r.l., Travagliato, Italy) is an open-source hardware (i.e., components) and software platform (an integrated development environment) used to create and control various projects and devices. Arduino was created in 2005 at the Interaction Design Institute Ivrea (Milan, Italy) to allow design-oriented students who are not familiar with computer devices to manipulate them easily. Arduino is commonly used in educational technology to enhance computer education in schools (Shim et al. 2016). A fan was installed on the lid to circulate the air in the terrarium. Because the fan operates when a button is pressed, both the fan and the button are necessary components. Jumper cables were used to connect the fan and buttons to the Arduino Uno board. The sequence of the component connections was not predetermined. For the coding activity, a program was input that allowed the fan to operate when the button was pressed. In the horticultural activity, soil was placed in a terrarium, and succulent plants were planted. For the activities that combined horticulture and coding, if pressing the button did not activate the fan, the component connections or codes could be modified. In addition,

succulent plants could be replanted or replaced (Table 1; Fig. 1).

MEASUREMENT. Brain waves, also known as electroencephalograms (EEGs), represent electrical signals reflecting the neural functional state of the brain (Min and Park 1980) and provide information about electrical activity in the brain (Kim et al. 2017). Brain waves emanating from the cerebral cortex are classified into theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–50 Hz), each indicating specific physiological functions (Sowndhararajan et al. 2015). Theta brain waves are observed during shallow sleep, alpha during relaxation and muscle relaxation, and beta during wakefulness and mental activity (Marzbani et al. 2016). In our study, the power spectrum analysis included the spectral edge frequency 50% of alpha (ASEF50) (8–13 Hz), indicating a comfortable, stable, and relaxed state; relative alpha (RA) [(8–13 Hz)/(4–50 Hz)], representing relaxation; RB [(13–30 Hz)/(4–50 Hz)], indicating active awareness; relative low beta (RLB) [(12–15 Hz)/(4–50 Hz)], indicating attention and alertness; relative mid beta (RMB) [(15–20 Hz)/(4–50 Hz)], indicating active awareness; ratio of SMR to theta (RST) [(12–15 Hz)/(4–8 Hz)], indicating focused attention; and ratio of mid beta to theta (RMT) [(15–20 Hz)/(4–8 Hz)], indicating concentrated focus. The spectral edge frequency 50% of alpha indicates a comfortable and stable relaxed state, whereas RST is an index representing focused attention (Lubar 1991; Ryu et al. 2013) (Table 2). Relative beta and RT increase as beta waves increase and theta waves decrease, indicating enhanced attention (Chabot and Serfontein 1996). Relative mid beta

Table 1. Connecting components, coding, horticultural activities, combined coding and horticultural activity description.

Activity	Description	
Connecting components	Manufacture of automatic irrigation system by combining two sets of eight parts including Arduino Uno (SZH-EK002; SMG; China), fan (SZH-GNP512; SMG; China), relay module (SZH-EK082; SMG; China), and so on, using the part connection manual.	Without plants
Coding	View code statements for automated irrigation systems and enter code into the Arduino integrated development environment software.	
Horticultural activities	Add soil to the terrarium container. Use hands to make a hole in the center of the container and plant the succulents in it. Press the soil. Use a brush to shake off the dirt on the leaves of the succulent plant. Succulents were <i>Pachyphytum</i> ‘Doctor Cornelius’ and were ~15 cm in size. The terrarium container was a 15-cm-diameter pot.	With plants
Combined coding and horticultural activity	Upload the fan actuation code to join the planter and the connected part, press the button, determine whether the fan starts, and observe the change code.	

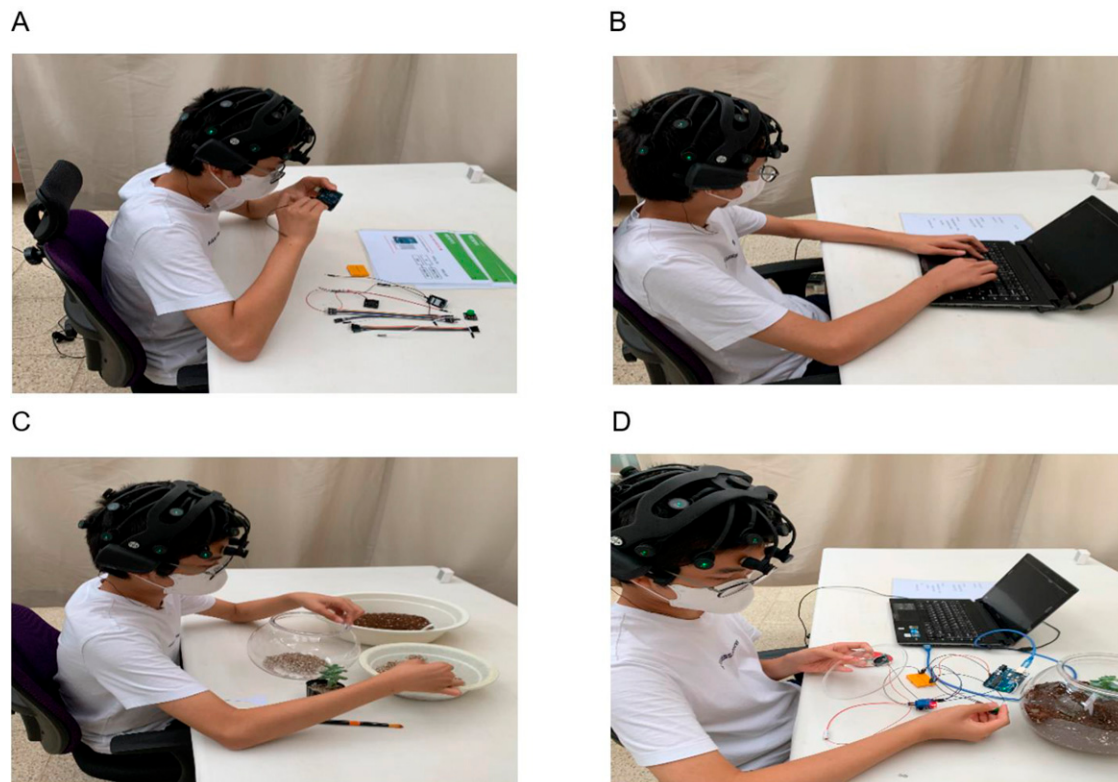


Fig. 1. Experimental performance appearance. (A) Connecting components. (B) Coding. (C) Horticultural activities. (D) Combined coding and horticultural activities.

and RLB increase when beta waves are subdivided during problem solving or logical thinking (Jang et al. 2014).

For each activity, a wireless, dry EEG device (Quick-20; Cognionics, San Diego, CA, USA) was used, which offers advantages such as reduced setup time and mobility (Okolo and Omurtag 2018). Data were obtained using brain mapping software (Bioteck Analysis; Bio-Tech, Daejeon, South Korea) to obtain average EEG measurements during the experiment. Electrodes were attached to the left earlobe according to the International 10–20 Electrode Placement System (Jasper 1958). In addition, electrodes were attached to a total of 20 channels, including sites such as the left prefrontal

pole (Fp1) and the right prefrontal pole (Fp2). In our study, the prefrontal cortex regions relevant to cognitive functions such as memory, attention, and emotional stability were analyzed (Banich et al. 2008; Miller and Cohen 2001).

The comparisons of a semantic differential method (SDM) is a questionnaire developed by Osgood (1952) for analyzing psychological meanings. In our study, the adjectives used were presented on a 13-point Likert scale that ranged from Very Comfortable to Very Uncomfortable, Very Natural to Very Artificial, and Very Relaxed to Very Awake. The scale was used to assess emotional states, with higher scores indicating more positive emotional states. To measure stress,

the stress state was measured at the end of each activity on an 11-point Likert scale from Low to High. An activity satisfaction survey was conducted after completing all activities: component connections, coding, horticultural activities, as well as coding and horticultural activity combination activities.

EXPERIMENTAL PROCEDURE. Participants underwent three practice sessions before the start of the study to familiarize themselves with the activities. They wore EEG devices that were placed with the help of a facilitator. Each activity was performed for 5 min, considering the time required for activity completion and referencing EEG measurements from a previous horticultural EEG study (Kim et al.

Table 2. Electroencephalographic power spectrum indicators used in this study.

Analysis indicators	Electroencephalographic power spectrum indicator	Wavelength range (Hz)	Explanation
ASEF50	Spectral edge frequency 50% of alpha	8–13	Comfortable, stable, relaxed
RA	Relative alpha	(8–13)/(4–50)	Relaxed
RB	Relative beta	(13–30)/(4–50)	Active awareness
RLB	Relative low beta	(12–15)/(4–50)	Attentive and alert
RMB	Relative mid beta	(15–20)/(4–50)	Active awareness
RST	Ratio of SMR (sensorimotor rhythm) to theta	(12–15)/(4–8)	Focused attention
RMT	Ratio of mid beta to theta	(15–20)/(4–8)	Concentrated focus

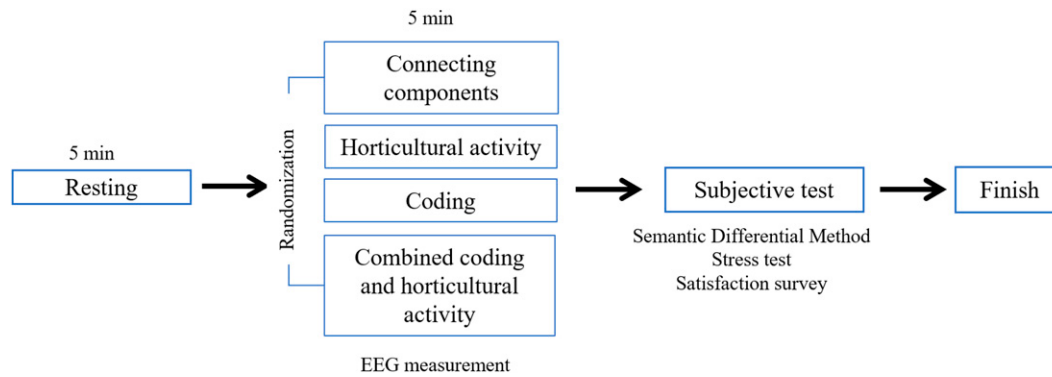


Fig. 2. Experimental protocol. After resting for 5 min, four activities were performed randomly for 5 min to measure brain waves. After the end of each activity, participants completed two subjective tests. EEG = electroencephalography.

2021; Oh et al. 2019). In addition, participants were advised to avoid excessive talking or movement during the activities because it could affect EEG measurements. After each task was completed, we assessed the participants' mental state during the activity using two questionnaires (SDM, Stress Test) (Fig. 1). A satisfaction survey was conducted after all activities were completed, and each activity lasted for ~45 min (Fig. 2).

DATA ANALYSIS. Electroencephalographic analysis was conducted using IBM SPSS Statistics for Windows v. 25 (IBM Corp., Armonk, NY, USA). One-way analysis of variance, followed by post hoc tests, Duncan's multiple range test, and two-sample *t* tests were used. All significance levels were set at $P < 0.05$. Demographic information was analyzed using Microsoft Excel (Microsoft Office 365 ProPlus; Microsoft, Redmond, WA, USA) to obtain descriptive statistics for sex and age.

Results

A total of 34 students, residing in Seoul and Gyeonggi Province, South Korea, between the ages of 11 and 16 years participated in the study (average age, 12.55 ± 1.73 years). To ensure the normality of the sample, skewness and kurtosis were examined. The analysis results showed that all values were <2 in absolute terms, indicating they met the criteria for a normal distribution. During the activities of connecting components and horticultural activities, the RA index, indicating physiological relaxation and stability of the prefrontal cortex, was significantly greater at Fp1 ($P < 0.05$). In the combined coding and horticultural activity task, there were significant differences in the spectral edge frequency 50% of alpha (ASEF50), a measure of comfort in the prefrontal cortex ($P < 0.001$). For the horticultural activities procedure, there was a significant difference in RST, an indicator of attention and concentration in the prefrontal cortex ($P < 0.001$) (Table 3).

The EEG analysis revealed that during the horticultural task and the combined coding and horticultural activity task, significant differences were observed in the power spectra of RB, RLB, RMB, RST, and RMT at Fp1 and Fp2 (left/right prefrontal lobe). These findings align with a previous study conducted by Jeong and Park in 2022, which showed increased activation in the RLB and RMB power spectra during plant-based coding activities in adults (Table 4).

The assessment of comparisons of an SDM based on coding-integrated activities revealed significantly high levels of comfort ($P < 0.01$), naturalness ($P < 0.001$), and relaxation ($P < 0.001$) during the horticultural activities task (Fig. 3). Stress analysis results and satisfaction reports indicated that the connecting components task showed significantly greater levels of stress ($P < 0.01$) (Fig. 4). In terms of satisfaction, the order of tasks was as follows: horticultural activities ($n = 23$, 64.7%), coding ($n = 12$, 32.4%), connecting components ($n = 1$, 2.9%), and combined coding and

Table 3. Results of the relative alpha, spectral edge frequency 50% of alpha, and ratio of sensorimotor rhythm to theta analysis according to electroencephalography (N = 34).

Activity	RA ⁱ		ASEF50 ⁱⁱ		RST ⁱⁱⁱ	
	Fp1 ^{iv}	Fp2 ^{iv}	Fp1	Fp2	Fp1	Fp2
Connecting components	0.16 ± 0.03 a ^v	0.17 ± 0.03	10.09 ± 0.23 c	10.06 ± 0.23 c	0.23 ± 0.09 b	0.22 ± 0.09 b
Coding	0.15 ± 0.03 ab	0.16 ± 0.03	14.15 ± 5.23 b	13.28 ± 5.22 b	0.20 ± 0.08 b	0.19 ± 0.07 b
Horticultural activities	0.17 ± 0.03 a	0.16 ± 0.03	9.98 ± 0.27 c	10.07 ± 0.20 c	0.32 ± 0.16 a	0.32 ± 0.15 a
Combined coding and horticultural activity	0.15 ± 0.03 b	0.16 ± 0.04	39.17 ± 0.83 a	38.93 ± 3.49 a	0.25 ± 0.11 b	0.23 ± 0.09 b
Significance ^{vi}	0.033*	0.860 NS	0.000***	0.000***	0.000***	0.000***

ⁱ Relative alpha (RA) power spectra were calculated by [Beta (8–13 Hz) power]/[Total frequency (4–50 Hz) power].

ⁱⁱ Alpha spectral edge frequency 50 (ASEF50) ratio of the sensorimotor rhythm to theta (RST) power spectra is the area from 8–13 Hz, which occupies 50% of the area in the entire frequency range.

ⁱⁱⁱ RST power spectra were calculated by [Theta (12–15 Hz) power]/[Total frequency (4–8 Hz) power].

^{iv} Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe.

^v Post hoc analysis shows a > b > c according to Duncan's multiple range tests.

^{vi} Statistical significance was determined using one-way analysis of variance.

NS, *, *** Nonsignificant or significant at $P < 0.05$ or 0.001, respectively.

Table 4. Results of the relative beta, relative low beta), relative mid beta, ratio of sensorimotor rhythm to theta, and ratio of mid beta to theta analysis according to electroencephalography (N = 34).

Activity	RB (mean $\pm$ SD) ⁱ		RLB (mean $\pm$ SD) ⁱⁱ		RMB (mean $\pm$ SD) ⁱⁱⁱ		RST (mean $\pm$ SD) ^{iv}		RMT (mean $\pm$ SD) ^v	
	Fp1 ^{vi}	Fp2 ^{vi}	Fp1	Fp2	Fp1	Fp2	Fp1	Fp2	Fp1	Fp2
Without plants	0.28 $\pm$ 0.06	0.27 $\pm$ 0.05	0.06 $\pm$ 0.01	0.07 $\pm$ 0.01	0.19 $\pm$ 0.15	0.17 $\pm$ 0.13	0.22 $\pm$ 0.08	0.20 $\pm$ 0.08	0.30 $\pm$ 0.14	0.28 $\pm$ 0.13
With plants	0.29 $\pm$ 0.06	0.29 $\pm$ 0.05	0.07 $\pm$ 0.01	0.07 $\pm$ 0.01	0.09 $\pm$ 0.02	0.09 $\pm$ 0.02	0.24 $\pm$ 0.10	0.23 $\pm$ 0.09	0.33 $\pm$ 0.18	0.32 $\pm$ 0.15
Significance ^{vii}	0.472 NS	0.012*	0.047*	0.028*	0.000***	0.000***	0.077 NS	0.012*	0.201 NS	0.018*

ⁱ Relative beta (RB) power spectra were calculated by [Beta (13–30 Hz) power]/[Total frequency (4–50 Hz) power]. SD = standard deviation.

ⁱⁱ Relative low beta (RLB) power spectra were calculated by [Beta (12–15 Hz) power]/[Total frequency (4–50 Hz) power].

ⁱⁱⁱ Relative mid beta (RMB) power spectra were calculated by [Beta (15–20 Hz) power]/[Total frequency (4–50 Hz) power].

^{iv} Ratio of sensorimotor rhythm to theta (RST) power spectra were calculated by [Theta (12–15 Hz) power]/[Total frequency (4–8 Hz) power].

^v Ratio of mid theta (RMT) power spectra were calculated by [Theta (15–20 Hz) power]/[Total frequency (4–8 Hz) power].

^{vi} Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe.

^{vii} Statistical significance as determined using a two-sample *t* test.

NS, *, *** Nonsignificant or significant at *P* < 0.05 or 0.001, respectively.

horticultural activity (n = 0, 0.0%) (Fig. 4).

Discussion

We aimed to investigate the psychophysiological and psychological effects of plant-based coding activities on students age 11 to 16 years. The activities were categorized into four types: “connecting components”, “coding”, “horticultural activities” and “combined coding and horticultural activity”. The EEG analysis results for each activity revealed that horticultural activities exhibited the highest values in the RA and RST power spectra within the frontal cortex. Moreover, the plant-based coding activities showed the highest values in the ASEF50 power spectrum within the frontal cortex (Table 2). Activities involving plants, such as horticultural and plant-integrated coding activities, demonstrated elevated power spectra in the delta band (RB), low beta band (RLB), middle beta band (RMB), RST, and RMT (Table 4). Self-report survey

results indicated high levels of comfort, naturalness, and relaxation during plant-related activities (Fig. 3).

During the horticulture activity, there was an increase in the ASEF50 index, indicating an activation of brain comfort. The ASEF50 index corresponds to the frequency range that encompasses 50% of the alpha frequencies (8–13 Hz). This range features predominantly fast alpha waves, signifying a state of relaxed and appropriately aroused stability and relaxation in the brain (Ryu et al. 2013). The faster frequency range of alpha waves is associated with a comfortable state for optimal performance and creative thinking (Bak et al. 2009). Prior studies related to horticultural and coding activities have shown an increase in the faster frequency range of alpha waves during horticultural activities (Jang et al. 2019). In addition, postcoding activity measurements indicated an enhancement in creative abilities compared with precoding

measurements (Kim and Hyun 2020). Therefore, it can be inferred that horticultural-based coding activities are associated with physiological relaxation and cognitive enhancement.

During the execution of horticultural-based coding activities, there was an observed increase in the RA power spectrum and RST index, indicating heightened concentration. Furthermore, while concurrently engaging in coding and horticultural activities, the RLB and RMB power spectra showed an elevation, corresponding to an increase in attentiveness. The RLB and RMB power spectra are subcategories of beta waves (Lim et al. 2019). The RLB power spectrum becomes active during problem solving without stress or tension, whereas the RMB power spectrum is associated with logical thinking, problem solving, and interest in external subjects (Jang et al. 2014). In a study conducted by Lee et al. (2018), horticultural activities led to a decrease in RT,

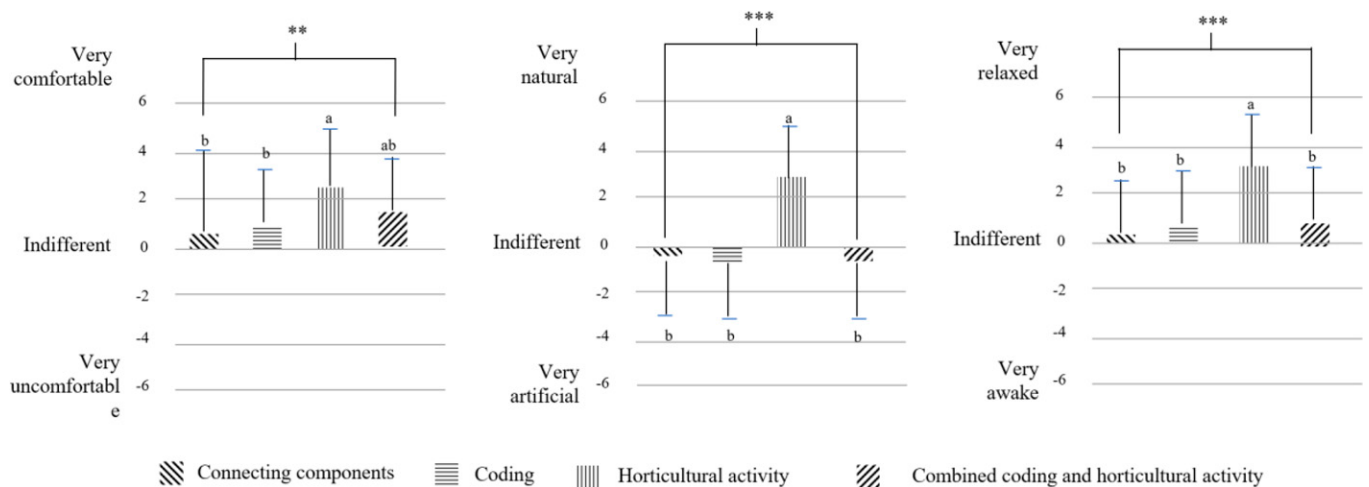


Fig. 3. Comparisons of a semantic differential method for each activity. There was a significant difference between horticultural activities (*P* < 0.01 and ****P* < 0.001) according to the one-way analysis of variance. Post hoc analysis: a > b according to Duncan's multiple range tests.**

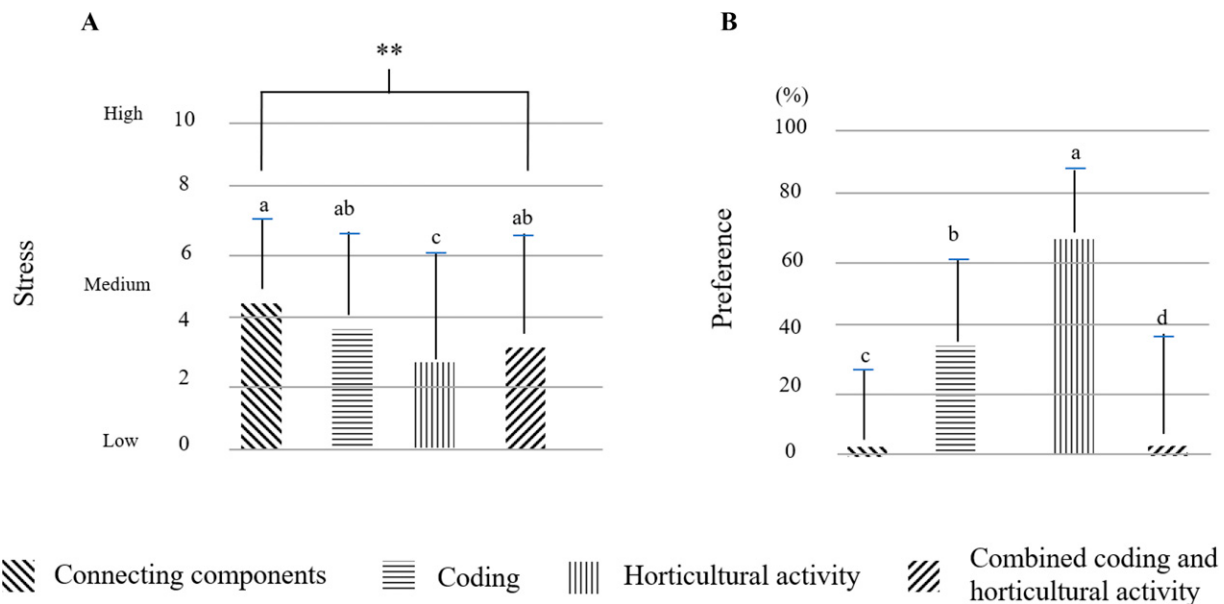


Fig. 4. (A) Stress for each activity. $P < 0.01$ according to one-way analysis of variance. Post hoc analysis: $a > b > c$ according to Duncan's multiple range tests. (B) As a result of the satisfaction survey, plants were ranked highly. Preference for each activity followed the order $a > b > c > d$.**

whereas RB and RMB exhibited an increase.

Existing research on coding has reported positive outcomes related to attitudes toward science through coding education (Alò et al. 2020), and enhancements in computational thinking and creativity (Fidai et al. 2020). Our study revealed that the integration of coding and plant-related activities, as well as plant-based activities themselves, can enhance cognitive functions such as concentration, problem solving, and logical thinking.

Long-term computer use was shown, in particular, to increase musculoskeletal symptoms in the neck, shoulders, hands, and wrists (Jensen et al. 2002a). When comparing horticultural activities with computer operation, horticultural activities have been associated with increased comfort, relaxation, and a natural feeling. These activities also lead to increased parasympathetic nervous system activity and decreased blood pressure, indicating both psychological and physiological relaxation (Lee et al. 2015). In addition, horticultural activities have been linked to improved upper limb and hand functionality (Park et al. 2013; Son et al. 2022) and enhanced balance perception among rehabilitation patients (Lee 2017).

Conclusion

Plant-based coding activities proved beneficial for enhancing attention and

concentration among students age 11 to 16 years. In particular, activities involving plants were found to increase participants' focus and comfort while also improving their subjective emotional states. This highlights the potential utility of plant-involved activities for enhancing concentration and promoting a sense of well-being among participants.

These findings have the potential to benefit the well-rounded development of students and to foster healthier computer use practices in educational environments. More extensive research and validation efforts are essential to confirm and build upon these results, thereby strengthening the basis for applying these findings within practical educational contexts.

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