Physiological and Psychological Responses to Coding Combined with Horticultural Activity

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Abstract. **This study was conducted to determine the physiological and psychological benefits of integrating software coding and horticultural activity. Participants included 30 adults in their 20s. The subjects randomly engaged in activities—namely, connecting Arduino components, coding, planting, and a combined coding and horticultural activities. During the activity, two subjective evaluations were conducted at the end of each activity, and participants' brain waves were measured. The spectral edge frequency 50% of alpha spectrum band (ASEF50) and ratio of sensorimotor rhythm from mid beta to theta (RSMT) were activated in the prefrontal lobe as participants performed combined coding and horticultural activities. When performing these combined activities, relative beta (RB) increased, and relative theta (RT) decreased in the prefrontal lobe. In addition, ASEF50, relative low beta (RLB), and relative mid beta (RMB) were activated during plant-based activities (planting and a combined coding and horticultural activities). The subjective evaluations revealed that the plant-based activities had a positive effect on participants' emotions. This study shows that activities combining coding and horticulture had a positive impact on physiological relaxation and increased concentration in adults compared with other activities and was also linked with positive subjectively reported emotions.**

As society has become more technologically advanced in the 21st century, the extent of computer coding education for elementary, middle, and high school students is rapidly increasing (Lee and Lee, 2018). In South Korea, elementary schools are required to provide more than 17 h of software education per semester in practical subjects, and middle schools must provide software education classes for more than 34 h per semester (Ministry of Education, 2015). Beyond elementary and middle schools, a software-oriented university project began in 2015, and nontechnical students are continuously incorporating software education into their schooling to contribute to innovations in the field of their major (Song, 2020). In addition, more universities are requiring students to participate in coding education, even in liberal arts programs (Shin et al., 2019). Meanwhile, the United States has developed CSTA K–12 Computer Science Standards to propose standards for computer science education that students should learn at different levels. The computer science contents of CSTA K–12 Computer Science Standards are presented in five key areas: Computational Thinking; Collaboration; Computing Practice and Programming; Computers and Communications Devices; and Community, Global, and Ethical Impacts (Kim and Lee, 2016). Coding in education is increasingly popular because universities have identified that software developed through coding represents a new domain of innovation and value creation (Kim et al., 2019).

Originally, most studies related to coding education were conducted on children and adolescents; however, since 2014, more research has been conducted with college students and adults (Heradio et al., 2018). Much of this research has considered coding education related to robotics; however, recently, coding education studies have converged with various fields to provide a more diverse perspective. Among environmental education programs using Arduino devices for elementary school students, education and development initiatives are being conducted in various fields, such as smart pot construction (Kim et al., 2018a), physical game software development using coding (Lee, 2020), and small-scale environmental monitoring using Arduino for adolescents (Alò et al., 2020). Research on coding education has demonstrated that it has several positive effects, including fostering a positive attitude toward science (Alò et al., 2020) and improved computer skills and creativity (Fidai et al., 2020). However, working with computers has disadvantages that occur physically and psychologically. When performing tasks using computers, prolonged repetition of tasks is associated with increased prevalence of musculoskeletal symptoms in the neck, shoulder, hand, and wrist (Jensen et al., 2002a, 2002b). In addition, computer activity reduces parasympathetic activity, which can lead to tension and stress (Garde et al., 2002; Hjortskov et al., 2004).

In contrast, horticultural activities are effective in restoring and improving physical, mental, and social health (Son et al., 2006). When older adults performed horticultural activities, levels of brain-derived neurotrophic factor increased, which improved cognitive function (Park et al., 2020). Moreover, horticultural activity programs can reduce anxiety and depression in older adults (Lee et al., 2016). Physically, various horticultural tasks can exercise large and small muscles in the upper and lower body (Park et al., 2013, 2014) and effectively improve hand function (Lee et al., 2018a). Research has also demonstrated that the brain activity and concentration of children engaging in math tasks increased in environments with plants (Kim et al., 2020). For adults, sympathetic nervous activity decreased when transplanting real plants and versus artificial ones (Lee et al., 2013). In addition, green indoor plants can improve heart rate and stimulate the autonomous nervous system to provide physiological stability (Choi et al., 2016).

This study was conducted to investigate the physiological and psychological responses of coding activities fused with horticultural activities to attenuate problems associated with computer work. Two activities using plants and two computer (coding) activities without plants were performed to compare brain waves and psychological conditions.

Materials and Methods

Participants. This study was conducted with 11 men and 19 women in their 20s. In previous psychophysiological studies on horticultural activities, a single experimental group without a control group included 30 participants. (Kim et al., 2020; 2021a). To recruit participants, a flyer with the study information was uploaded on social networking service (SNS), and other subjects were recruited through subjects who completed the study using a snowball sampling method. The participants were all right-handed based on previous research by Tarkka and Hallett (1990) demonstrating that left-handed compared with right-

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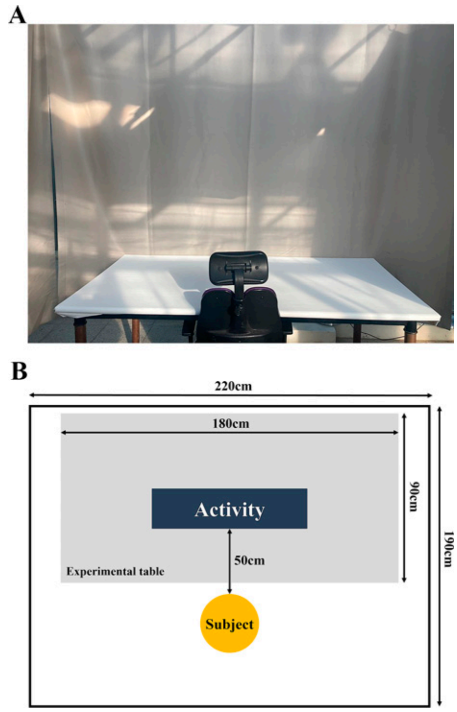

Fig. 1. Experimental area: (**A**) experimental room and (**B**) arrangement during the experiment.

handed people differ in their brain activity. Subjects currently suffering from a specific disease were also excluded (Choi et al., 2016). Participants were asked to fast for 2 h before the experiment to eliminate the potential effects of naturally occurring caffeine in various foods that could stimulate the brain (Heckman et al., 2010). Before the experiment, participants received an explanation of the details of the study, after which they provided their informed consent, and their demographic information was collected through a questionnaire. Subsequently, the participants' height, weight, and body mass index (BMI; ioi 353; Jawon Medical, Gyeongsan, South Korea) were measured, and coding and plant training was conducted. This study was conducted with the approval of Konkuk University's Institutional Bioethics Committee (7001355-202004-HR-376).

Experimental condition. This experiment was conducted in a 2.2 m × 1.9 m space in Konkuk University's experimental area. Environmental factors within the space were kept constant, including an average temperature of 24.67 ± 2.94 °C, average humidity of 29.00% ± 10.80%, and average light intensity of 3405.30 ± 1638.37 lux. To minimize the potential influence of external stimuli during the experiment, ivory curtains were installed at the front and on both sides of the experiment space, and white sheets were attached to the desk. The height of the chair was adjusted according to the participants' heights, and chairs were positioned at the center of the desk (Fig. 1).

Activities. In this study, coding and horticultural activities to make automatic watering pots were divided into four phases, including the connecting Arduino component, planting, coding, and the combined coding and horticultural activities. In the task that involved connecting Arduino components, underwater pump motors and soil moisture sensors needed for automatic watering pots were connected to Arduino Uno. For coding activities, the code needed to operate an automatic watering pot was entered. Planting tasks involved planting 9-cm-diameter pots with an indoor foliage plant (Scindapsus; *Epipremnumaureum*). In the combined coding and horticultural task, the plant and the automatic watering system were combined and operated, and the code was changed (Table 1; Fig. 2).

Experimental procedure. Training was conducted for 30 min to instruct participants on how to make the automatic plant irrigation system and to provide general education on coding and plants. After training, the participants sat on a chair in the experimental area, were asked to wear a wireless brain-wave measurement device, and were given an explanation of the relevant precautions. To adapt to the electroencephalogram measuring device, the participants sat in the experimental area for 5 min while looking straight ahead as the machine stabilized. Four activities were then performed in random order: connecting the components, planting, coding, and the combined coding and horticultural task. Each activity was performed for 5 min by referring to an electroencephalograph (EEG) measurement study on horticultural activities and considering the time needed to complete the activity (Oh et al., 2019; Kim et al., 2021a, 2021b). In addition, participants were requested to avoid speaking or moving more than necessary because such movements may influence the brain-wave measurements. After each task was completed, two questionnaires were used to evaluate the participants' state of mind during the activity, and the experiment was ended after performing all four tasks in this manner (Fig. 3). The average experimental time per subject was ≈45.03 ± 5.46 min.

Measurement. Brain waves refer to electrical signals indicating the state of the brain's neural function in the cerebral cortex (Min and Park, 1980) and are useful sources of information for interpreting and analyzing human thoughts and emotions (Kim et al., 2017). Brain waves from the cerebral cortex are classified as theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–50 Hz) waves, respectively, with each indicating specific physiological functions (Sowndhararajan et al., 2015). Theta waves are observed during shallow sleep, alpha waves during a state of relaxation and muscle loosening, beta waves during a state of awakening and mental activity, and gamma waves when trying to solve problems (Marzbani et al., 2016). This study measured the ASEF50, RSMT, RB power spectrum, RT power spectrum, RMB power spectrum, and RLB power spectrum to examine the brain's comfort level and concentration of participants as evidenced by the information collected during each task.

Table 1. Description of activities.

Activity	Description	
Connecting Arduino components	Manufacture of automatic irrigation system by combining two sets of eight parts including Arduino Uno (SZH-EK002; SMG, Guangdong, China), Soil Moisture Sensor (SZH-EK106; SMG-A, Guangdong, China), Underwater Pump Motor (SZH-GNP155, SMG), LCD Module (I2C LCD1602, SMG), Relay Module (SZH-EK082, SMG), etc. with part connection manual.	Without plants
Coding	View code statements for automated irrigation systems and enter code into the Arduino IDE (Integrated Development Environment) software.	
Planting	Planting Scindapsus (*E. aureum*) in a 9-cm-diameter pot.	With plants
Combined coding and horticultural activity	Combine the potting the plant and connecting components by the Scindapsus (*E. aureum*), upload the code, check if it is automatically irrigated according to the moisture content in the soil, and change and observe the code.	With plants

ASEF50 indicates a comfortable, stable and relaxed state, and RSMT is an indicator of attention (Lubar, 1991; Ryu et al., 2013). RB and RT are used as concentration indicators, and as beta waves increase and theta waves decrease, attention increases (Chabot and Serfontein, 1996). RMB and RLB increase when solving problems or thinking logically by subclassifying beta waves (Jang et al., 2014). In this work, we used a wireless dry EEG device (Quick-20; Cognionics, San Diego, CA) (Fig. 4A). This device minimized the risk of electric shock compared with wet electrode systems that use an electrolyte gel (Kim et al., 2021b). In addition, it has the advantage of quicker setup time, increased versatility, and improved mobility (Okolo and Omurtag, 2018). The difference in electrical potential is obtained by placing the dry electrodes on the scalp to amplify and collect the measured electrical signals. The device is primarily used in neuroscience and is certified safe by the European Commission and the Federal Communications Commission. The data obtained average EEG measurements during the experiment using a brain-mapping program (Bioteck Analysis; Bio-Tech, Daejeon, Korea).

The electrodes were attached to the left earlobe (A1), according to the International 10-20 Electrode Placement System (Jasper, 1958). In addition, the electrodes were attached to a total of eight channels including left prefrontal lobe (Fp1), right prefrontal

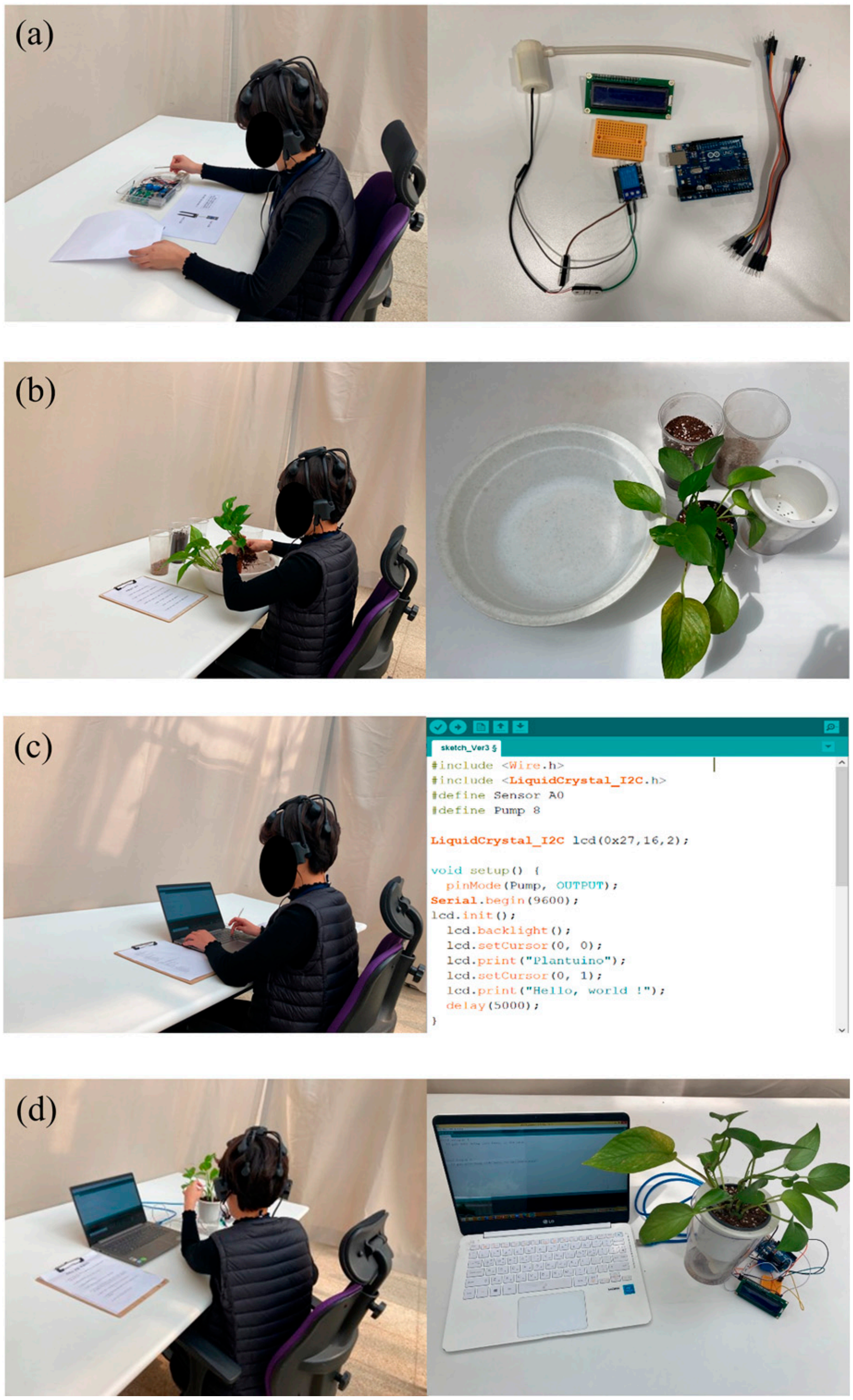

Fig. 2. Experimental performance appearance: (**A**) connecting Arduino components, (**B**) planting, (**C**) coding, and (**D**) combined coding and horticultural activities.

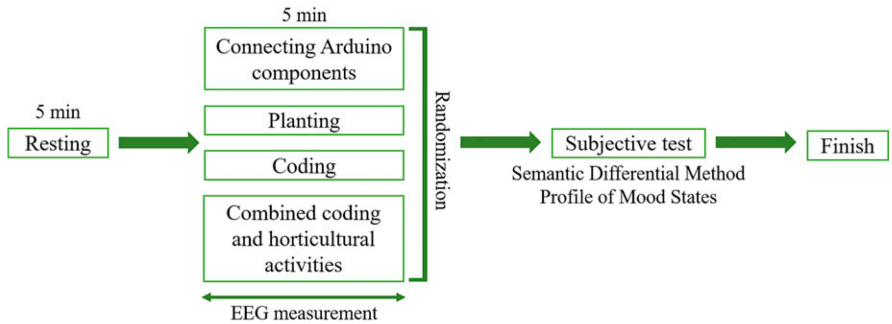

Fig. 3. Experimental protocol. EEG = electroencephalography. After resting for 5 min, four activities were randomly performed for 5 min to measure brain waves. After the end of each activity, participants completed two subjective tests.

lobe (Fp2), left frontal lobe (F3), right frontal lobe (F4), left parietal lobe (P3), right parietal lobe (P4), left occipital lobe (O1), and right occipital lobe (O2) to measure brain waves (Fig. 4B). In this study, prefrontal lobes related to cognitive functions such as memory, attention, and emotional processes were analyzed (Banich et al., 2008; Miller and Cohen, 2001).

The Semantic Differential Method (SDM) is a questionnaire developed by Osgood (1952) in which participants choose between pairs of adjectives that evaluate the ways in which their emotional state changes with their environment. The three pairs of adjectives are "very comfortable–very uncomfortable," "very natural–very artificial," and "very relaxed–very awake," with a 13-step scale ranging from –6 to +6. For each emotional state item, the higher the value, the more positive the emotional state.

The Profile of Mood States (POMS) questionnaire was developed by McNair et al. (2003). It measures several factors—namely, tension and anxiety, depression, anger-hostility, vigor, confusion, and fatigue—as a way of assessing the temporary mood or emotional state of the participant. Each question asked participants how well each of the emotions described how they felt "right now" and was scored on a 5-point scale from "not at

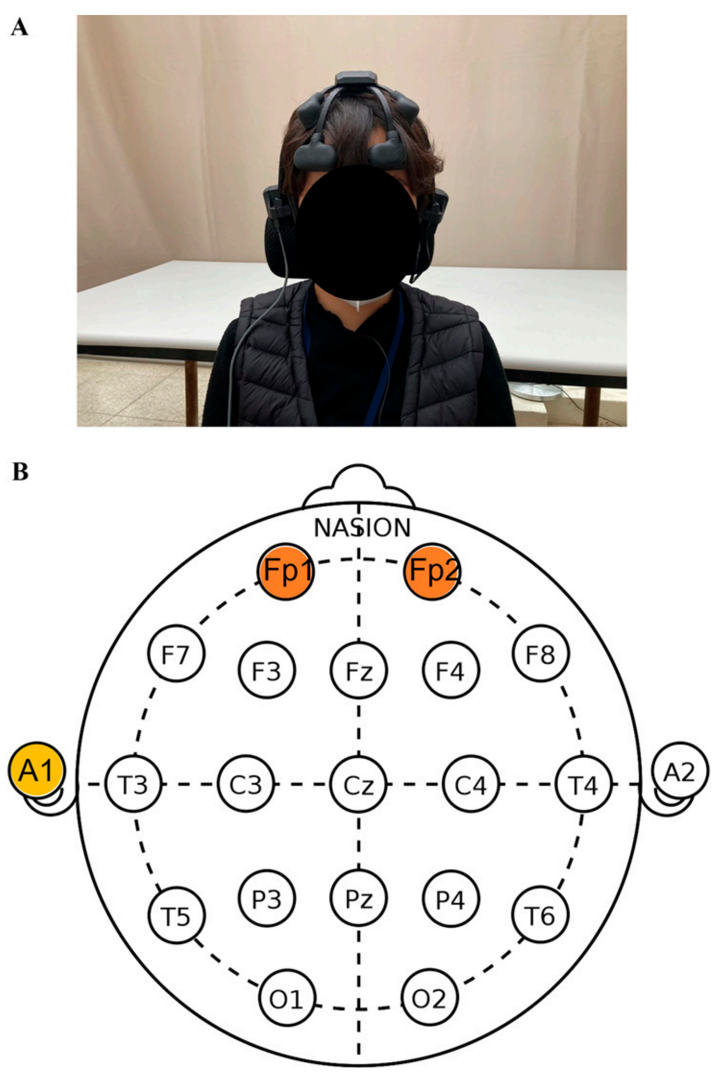

Fig. 4. (**A**) Wireless dry electroencephalography device (Quick-20; Cognionics, San Diego, CA). (**B**) International electrode arrangement (Jasper, 1958).

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Table 2. Electroencephalography (EEG) power spectrum indicators used in this study (Sowndhararajan et al., 2015).

Analysis indicators	Full name of the EEG power spectrum indicator	Wavelength range (Hz)
ASEF50	Spectral edge frequency 50% of alpha	8–13
RB	Relative beta	(8–13)/(4–50)
RT	Relative theta	(4–8)/(4–50)
RMB	Relative mid beta	(15–20)/(4–50)
RLB	Relative low beta	(12–15)/(4–50)
RSMT	Ratio of SMR mid beta to theta	(12–20)/(4–8)

all" (1) to "extremely" (5), and then the Total Mood Disorder (TMD) score was evaluated by summing the values of each question. The lower the value, the more positive the emotional state of the participant.

Data analysis. Brain-wave analysis is based on Bioteck's Analysis software. The frequencies used in this study were analyzed for ASEF50; RB, RT, RMB, and RLB power spectrums; and RSMT (Table 2). Statistical analysis of brain waves was performed using IBM SPSS Statistics for Windows (version 25; IBM Corp., Armonk, NY) to perform one-way analysis of variance tests, Kruskal-Wallis tests and Duncan's multiple range tests, two-sample t tests and Mann-Whitney U tests. All significance levels were set at $P < 0.05$. Demographic information was analyzed with Microsoft Excel (Microsoft Office 365 ProPlus; Microsoft, Redmond, WA) to provide descriptive statistics for gender, age, height, weight, and BMI for average, standard deviation, and percentage.

Results

Demographic characteristics. The study involved 30 adults in their 20s (36.7% men and 63.3% women). Participants' demographic information is shown in Table 3.

Results of brain-wave analysis by activity type. According to the ASEF50 analysis, the left prefrontal lobe was more active during combined coding and horticultural activities than other activities ($P < 0.01$). For the right prefrontal lobe, ASEF50 analysis indices were significantly higher during combined coding and horticultural activities, planting, and component connection tasks than during coding ($P < 0.001$). Analysis of the ASEF50 of men and women revealed that on average, men had a higher during the combined coding and horticultural activity, and this was significantly different from the other activities (Supplemental Table 1) (Fp1: $P < 0.05$, Fp2: $P < 0.01$), but no such significant differences were found in women. The RSMT analysis was significantly higher during the combined coding and horticultural, connecting components, and planting tasks in the left prefrontal lobe compared with coding ($P < 0.01$), and significantly higher during the combined coding and horticultural task in the right prefrontal lobe than during the other activities ($P < 0.01$). There was no significant difference between each activity between men and women (Table 4).

The RB power spectrum analysis showed that RB was significantly higher during the combined coding and horticultural activity and the component connecting activity than the other activities in the left prefrontal lobe ($P < 0.05$). RB was also significantly higher in the right prefrontal lobe during the combined coding and horticultural activity than the other activities ($P < 0.05$). In contrast, RT power spectrum analysis showed significantly lower in the left prefrontal lobe during a combined coding and horticultural activities ($P < 0.05$). There were no significant differences based on sex in terms of the RB and RT power spectrums (Table 5).

Result of brain-wave analysis by the presence of plants. An analysis was conducted by dividing the tasks into plant-free and plant-based tasks. From the ASEF50 analysis, plant-based combined planting activity (the planting and combined coding/horticultural tasks) resulted in significantly increased activity in both prefrontal lobes ($P < 0.05$). An analysis of sex differences showed a significant increase in right prefrontal lobe activity during plant-based tasks for men ($P < 0.05$), but no significant differences were found for women. The RLB power spectrum analysis showed a significant increase in activity in both prefrontal lobes during the plant-based combined planting task ($P < 0.05$). An analysis of sex differences showed no significant differences for male participants, but for females, plant-based tasks significantly increased activity in the left prefrontal lobe ($P < 0.05$). The RMB power spectrum analysis showed a significant increase in activity in the right prefrontal lobe during plant-based tasks ($P < 0.05$). There was no significant difference between tasks when comparing men and women (Table 6).

Subjective emotion assessment. In the SDM assessment, emotions associated with each coding and plant task showed significantly higher "comfort" ($P < 0.01$), "natural" ($P < 0.001$), and "relaxed" ($P < 0.001$) feelings when performing plant-based activities (Fig. 5).

As noted earlier, the POMS was divided into six areas for analysis (Fig. 6A). The tension-anxiety and fatigue scores was significantly lower during planting and combined coding and horticultural tasks than the other activities ($P < 0.01$). Vigor was significantly higher during the planting activity ($P < 0.001$), and there were no significant differences for depression, anger-hostility, or confusion. Analysis of TMD, the sum of the six regions (Fig. 6B), revealed that there were significantly lower TMD scores during the planting and the combined coding and horticultural activity ($P < 0.001$).

Discussion

This study was conducted to understand the psychophysiology and psychological effects of integrating coding and horticultural activity in adults.

As a result of the EEG analysis obtained by dividing the integrated coding and horticultural activity into four types, the ASEF50 and RSMT and RB power spectrums were found to be highest in the prefrontal lobe when a combined coding and horticultural task was performed, whereas the RT power spectrum was lowest. In addition, EEG analysis indicated that ASEF50, and the RLB and RMB power spectrums showed the highest activity during tasks that involved plants (the combined planting task) in the prefrontal lobe. As a result of the subjective questionnaire, comfortable, natural, and relaxed feelings were high during planting activities, and TMD scores were low in planting and the combined activity.

When a combined coding and horticultural task and a plant-based activity with plants were performed, the ASEF50 index increased, and brain comfort was activated. ASEF50 is a region corresponding to 50% of the alpha wave frequency band (8–13 Hz), and there are many fast alpha waves, indicating that the brain is comfortable and in a stable and relaxed state with appropriate arousal (Ryu et al., 2013). The fast frequency region

Table 3. Descriptive characteristics of participants.

Variable	Male	Female	Total
	Mean ± SD		
% (N)[z]	36.7 (11)	63.3 (19)	100 (30)
Age (years)	26.36 ± 1.96	26.47 ± 1.90	26.43 ± 1.89
Height (cm)	175.55 ± 3.14	159.56 ± 7.21	165.62 ± 9.87
Body weight (kg)	75.28 ± 9.34	57.34 ± 8.74	64.15 ± 12.49
Body mass index ($kg \cdot m^{-2}$)[y]	23.43 ± 3.26	22.83 ± 3.43	23.43 ± 3.26

[z]% (N), percent (number of people).

[y]Body mass index = weight/height^2.

Table 4. Results of the spectral edge frequency 50% of alpha (ASEF50) and ratio of SMR mid beta to theta (RSMT) power spectrum, according to electroencephalography (EEG).

EEG	Activity	ASEF50[z] Fp1	ASEF50[z] Fp2	RSMT[y] Fp1	RSMT[y] Fp2
		Mean ± SD			
Male (n = 11)	Connecting Arduino components	10.09 ± 0.18	10.09 ± 0.14	0.55 ± 0.12	0.56 ± 0.14
	Planting	10.07 ± 0.17	10.09 ± 0.10	0.52 ± 0.12	0.55 ± 0.11
	Combined coding and horticultural activities	10.15 ± 0.08	10.14 ± 0.09	0.54 ± 0.07	0.57 ± 0.09
	Coding	9.98 ± 0.11	9.95 ± 0.10	0.43 ± 0.12	0.44 ± 0.12
	Significance[x]	0.020*	0.003**	0.082[NS]	0.050[NS]
Female (n = 19)	Connecting Arduino components	9.95 ± 0.10	9.99 ± 0.14	0.41 ± 0.10	0.43 ± 0.09
	Planting	9.97 ± 0.10	10.02 ± 0.12	0.42 ± 0.10	0.43 ± 0.10
	Combined coding and horticultural activities	10.02 ± 0.12	10.04 ± 0.14	0.45 ± 0.11	0.48 ± 0.13
	Coding	9.91 ± 0.16	9.92 ± 0.16	0.35 ± 0.11	0.39 ± 0.15
	Significance[x]	0.050[NS]	0.066[NS]	0.065[NS]	0.096[NS]
Total (N = 30)	Connecting Arduino components	10.00 ± 0.15 ab[w]	10.03 ± 0.14 a	0.46 ± 0.13 a	0.48 ± 0.13 ab
	Planting	10.00 ± 0.14 ab	10.05 ± 0.12 a	0.46 ± 0.12 a	0.48 ± 0.11 ab
	Combined coding and horticultural activities	10.06 ± 0.12 a	10.07 ± 0.14 a	0.48 ± 0.11 a	0.51 ± 0.13 a
	Coding	9.93 ± 0.14 b	9.93 ± 0.14 b	0.38 ± 0.12 b	0.41 ± 0.14 b
	Significance[v]	0.006**	0.000***	0.009**	0.009**

[z]ASEF50 is area from 8 to 13 Hz that occupies 50% of the area in the entire frequency range.
[y]RSMT was calculated by [SMR-mid beta (12 to 20 Hz) power]/[theta (4 to 8 Hz) power].
[x]Statistical significance as determined using Kruskal-Wallis tests.
[w]Statistical significance as determined using Duncan's multiple range tests.
[v]Statistical significance as determined using one-way analysis of variance.
Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe. Post-hoc analysis: a > b by Duncan's multiple range tests.
[NS], *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

of alpha waves is related to a relaxed state or creative thinking for optimal performance (Bak et al., 2009). In previous studies related to horticultural and coding activities, when horticultural activity was performed, the fast frequency range of alpha waves increased (Jang et al., 2019), and after the coding activity, creative capability increased compared with measurements before the coding activity (Kim and Hyun, 2020), In other words, it was found that coding combined with a horticultural activity was associated with physiological relaxation and improvements in cognitive function.

When a combined coding and horticultural activity was performed, the index and RB power spectrum of RSMT increased, and RT power spectrum decreased, resulting in increased concentration. The RSMT can objectively confirm the state of concentration, and as the number increases, attention increases (Kim et al., 2018b; Lubar, 1991). Chabot and Serfontein (1996) stated that in people with attention problems, the theta wave increases in the frontal lobe and the beta wave frequency decreases.

In addition, during a combined coding and horticultural task and a planting task, the concentration of attention increased as the RLB and RMB power spectrums increased. The RLB and RMB power spectrums are subclassifications of beta waves (Lim et al., 2019). The RLB power spectrum is active when solving problems without stress or tension, and the RMB power spectrum appears during logical thinking, problem-solving, and interest in external objects (Jang et al., 2014). In a study conducted by Lee et al. (2018b), when horticultural activity was performed, RT decreased while RB and RMB increased. In a study done by Kim et al. (2021a), RT decreased and RSMT increased during

Table 5. Results of the relative beta (RB) and relative theta (RT) analysis according to electroencephalography (EEG).

EEG	Activity	RB[z] Fp1	RB[z] Fp2	RT[y] Fp1	RT[y] Fp2
		Mean ± SD			
Male (n = 11)	Connecting Arduino components	0.29 ± 0.03	0.29 ± 0.03	0.31 ± 0.07	0.30 ± 0.06
	Planting	0.28 ± 0.03	0.29 ± 0.02	0.32 ± 0.07	0.30 ± 0.05
	Combined coding and horticultural activities	0.29 ± 0.02	0.30 ± 0.02	0.29 ± 0.04	0.29 ± 0.04
	Coding	0.26 ± 0.04	0.26 ± 0.03	0.35 ± 0.08	0.35 ± 0.06
	Significance[x]	0.160[NS]	0.067[NS]	0.357[NS]	0.117[NS]
Female (n = 19)	Connecting Arduino components	0.25 ± 0.04	0.26 ± 0.03	0.37 ± 0.07	0.37 ± 0.06
	Planting	0.25 ± 0.04	0.26 ± 0.03	0.37 ± 0.06	0.36 ± 0.06
	Combined coding and horticultural activities	0.27 ± 0.03	0.27 ± 0.04	0.35 ± 0.06	0.34 ± 0.07
	Coding	0.23 ± 0.04	0.24 ± 0.05	0.40 ± 0.08	0.38 ± 0.09
	Significance[x]	0.103[NS]	0.118[NS]	0.199[NS]	0.160[NS]
Total (N = 30)	Connecting Arduino components	0.26 ± 0.04 a[w]	0.27 ± 0.04 ab	0.35 ± 0.07 ab	0.34 ± 0.07
	Planting	0.26 ± 0.04 a	0.27 ± 0.03 ab	0.35 ± 0.07 ab	0.34 ± 0.06
	Combined coding and horticultural activities	0.28 ± 0.03 a	0.28 ± 0.03 a	0.33 ± 0.06 b	0.32 ± 0.06
	Coding	0.24 ± 0.04 b	0.25 ± 0.04 b	0.38 ± 0.08 a	0.37 ± 0.08
	Significance[v]	0.014*	0.013*	0.044*	0.055[NS]

[z]RB power spectrum was calculated by [beta (8 to 13 Hz) power]/[total frequency (4 to 50 Hz) power].
[y]RT power spectrum was calculated by [theta (4 to 8 Hz) power]/[total frequency (4 to 50 Hz) power].
[x]Statistical significance as determined using Kruskal-Wallis tests.
[w]Statistical significance as determined using Duncan's multiple range tests.
[v]Statistical significance as determined using one-way analysis of variance.
Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe. Post-hoc analysis: a > b by Duncan's multiple range tests.
[NS], *, **, ***Nonsignificant or significant at $P < 0.05$, $P < 0.01$, or $P < 0.001$, respectively.

Table 6. Results of the spectral edge frequency 50% of alpha (ASEF50), relative low beta (RLB), and relative mid beta (RMB) according to electroencephalography (EEG).

		ASEF50[z]		RLB[y]		RMB[x]	
		Fp1	Fp2	Fp1	Fp2	Fp1	Fp2
EEG	Activity	Mean ± SD					
Male	Without plants	10.03 ± 0.13	10.02 ± 0.01	0.07 ± 0.01	0.07 ± 0.00	0.09 ± 0.01	0.09 ± 0.01
(n = 11)	With plants	10.11 ± 0.09	10.12 ± 0.07	0.07 ± 0.00	0.07 ± 0.00	0.09 ± 0.00	0.09 ± 0.01
	Significance[u]	0.101[NS]	0.023*	1.000[NS]	0.116[NS]	0.193[NS]	0.151[NS]
Female	Without plants	9.93 ± 0.13	9.95 ± 0.14	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
(n = 19)	With plants	9.99 ± 0.11	10.03 ± 0.122	0.07 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
	Significance[w]	0.080[NS]	0.116[NS]	0.032*	0.172[NS]	0.075[NS]	0.070[NS]
Total	Without plants	9.97 ± 0.14	9.98 ± 0.13	0.06 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
(n = 30)	With plants	10.03 ± 0.11	10.06 ± 0.11	0.07 ± 0.01	0.07 ± 0.01	0.09 ± 0.01	0.09 ± 0.01
	Significance[v]	0.047*	0.013*	0.037*	0.044*	0.058[NS]	0.021*

[z]ASEF50 is area from 8 to 13 Hz, which occupies 50% of the area in the entire frequency range.

[y]RLB power spectrum was calculated by [low beta (12 to 15 Hz) power]/[total frequency (4 to 50 Hz) power].

[x]RMB power spectrum was calculated by [mid beta (15 to 20 Hz) power]/[total frequency (4 to 50 Hz) power].

[w]Statistical significance as determined using Mann-Whitney *U* test.

[v]Statistical significance as determined using two-sample *t* test.

Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe.

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

horticultural tasks. In previous studies related to coding, positive studies were reported on the improvement of attitude toward science through coding education (Alò et al., 2020) and improvement of computational thinking and creativity (Fidai et al., 2020). In other words, it was found that the combined coding and plant activity and the plant-based activity were improved cognitive functions such as concentration, problem-solving, and logical thinking.

There are no studies measuring brain waves for activities that combined coding and horticulture compared with coding alone. Therefore, it seems that the results of this study can be explained in terms of STEM education. STEM education is short for science, mathematics, engineering, and technology and was established by the U.S. National Science Foundation to enhance creativity and thinking skills (White, 2014). Currently in South Korea, this concept is termed "STEAM" by adding A to the program (Arts), and the purpose is to cultivate convergent thinking by adding the sensibility of art (An and Yoo, 2015). As such, convergence of various fields has been applied to educational policies and is thought to maximize the effectiveness of education. Likewise, in this study, the reason why combined coding and plant tasks increased creativity and concentration compared with other activities may be related to convergence education.

As determined using the SDM and POMS, comfortable, natural, and relaxed feelings were higher and mood states were improved during tasks involving plants. In a previous study, when performing tasks with or without plants, comfortable, natural, and relaxed states were all high in tasks with plants, and the TMD score was lower, indicating a positive mood state (Park et al., 2017). Also, when comparing plant transplantation and computer operations, comfort, relaxation, and natural feelings all increased in plant transplantation, parasympathetic nerve activity increased, and blood pressure decreased, resulting in psychological and physiological relaxation (Lee et al., 2015). Similar to the results of a previous study that demonstrate that activities using plants improve subjective emotional and mood states compared with other activities, the results of this study also showed a positive emotional state in activities using plants.

The rapid development of modern information and communication technology and the negative effects of widespread use on human health have been studied. It has been reported that prolonged computer use has negative effects related to mental health, such as sleep disorders and depression (Thomée et al., 2012). Computer use has also been shown to decrease parasympathetic nerves, increasing tension and stress (Hjortskov et al., 2004). In addition, prolonged computer use was found to increase musculoskeletal

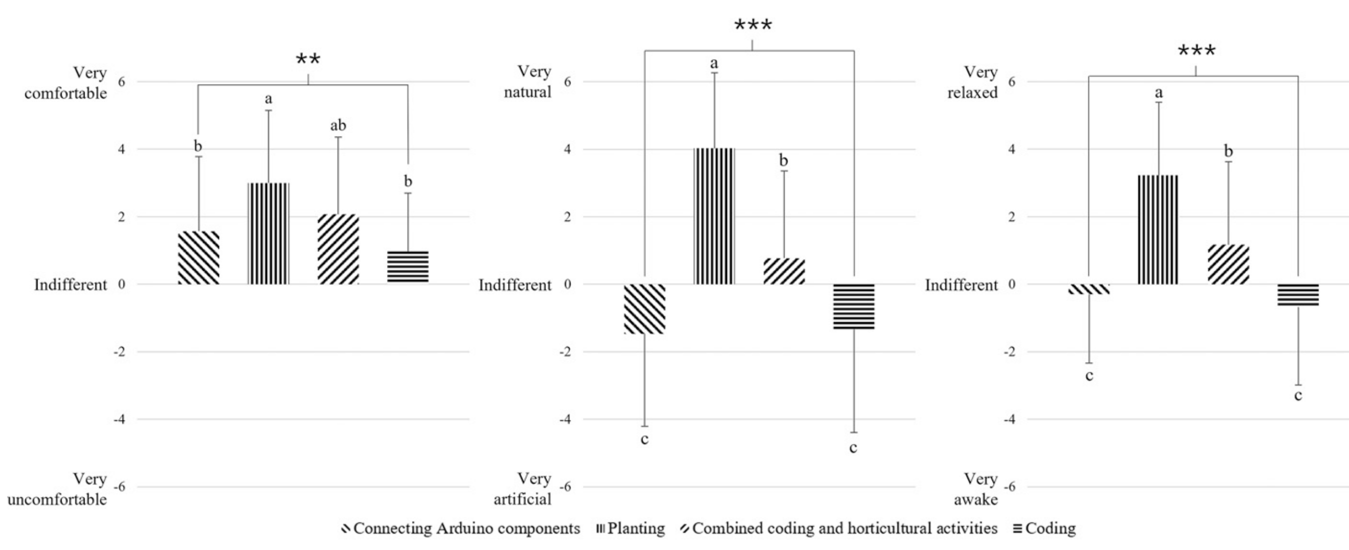

Fig. 5. Comparisons of the Semantic Differential Method (SDM) for each activity (N = 30). $^{**}P < 0.01$ and $^{***}P < 0.001$ according to the one-way analysis of variance. Post hoc analysis: a > b > c according to Duncan's multiple range tests.

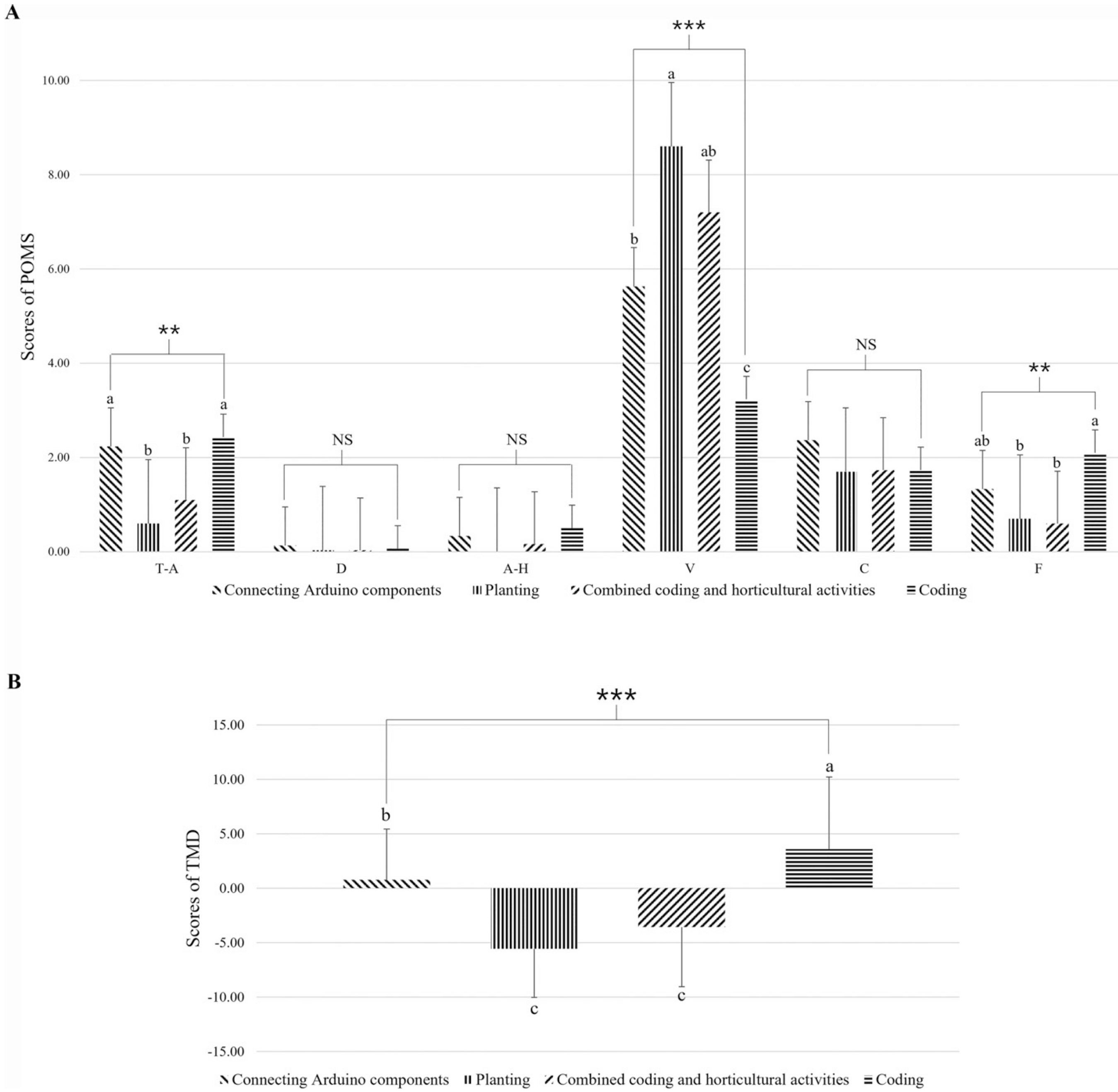

Fig. 6. (**A**) Comparisons of tension-anxiety (T-A), depression (D), anger-hostility (A-H), vigor (V), confusion (C), and fatigue (F) in the Profile of Mood State (POMS) for each activity (N = 30). (**B**) Comparisons of the Total Mood Disturbance (TMD) score on the POMS questionnaire between conditions (N = 30). NS = nonsignificant; $^{**}P < 0.01$ and $^{***}P < 0.001$ according to the one-way analysis of variance. Post hoc analysis: a > b > c according to Duncan's multiple range tests.

system symptoms, particularly in the neck, shoulder, hand, and wrist (Jensen et al., 2002a). In contrast, many studies have shown that horticultural activities may increase relaxation and have positive psychological and physical effects, as well as increased parasympathetic nerves (Lee et al., 2015, 2018a; Park et al., 2013, 2014). Physical and psychological problems caused by computer use may be attenuated by combining horticultural and computer activities; this could be applied as an intervention program to improve emotional development and concentration.

In conclusion, an integrated coding and plant activity was helpful in improving the attention and concentration of adults; in particular, the activities in this study that included plants increased the concentration and comfort of participants and was effective in improving subjective emotional states. This study investigated the mechanisms for the psychophysiology and psychological effects of interventions that combine computer science and horticulture. Our experimental results suggest the possibility of applying horticulture as an intervention program to improve emotional states and cognition by integrating plants and coding activities. In addition, it is thought that computer engineering tasks combined with horticultural activities can attenuate physical and psychological problems caused by computer use and thus improve emotional development and concentration. The results of this study can be used as basic data for program development and design using green plants. Coding education combined with horticulture is expected to be attempted, and application of such programs may be expanded to clinical treatments using plants. In the future, research with different age groups should be conducted, as well as studies in fields such as the arts, humanities, and horticulture. Further, the convergence of horticulture and engineering should be investigated in terms of its psychophysiology and psychological effects on humans.

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Supplemental Table 1. Results of the spectral edge frequency 50% of alpha (ASEF50), according to electroencephalography (EEG).

EEG	Group 1 – Group 2	ASEF50	
		Fp1	Fp2
		Significance[z]	
Male (n = 11)	Coding – connecting Arduino components	0.634[NS]	0.113[NS]
	Coding – planting	0.252[NS]	0.055[NS]
	Coding – combined coding and horticultural activities	0.012*	0.002**
	Connecting Arduino components – planting	1.000[NS]	1.000[NS]
	Connecting Arduino components – combined coding and horticultural activity	0.851[NS]	1.000[NS]
	Planting – combined coding and horticultural activity	1.000[NS]	1.000[NS]

[z]Statistical significance as determined using Kruskal-Wallis tests.

Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe.

[NS], *, **Nonsignificant or significant at $P < 0.05$ or $P < 0.01$, respectively.