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Psychophysiological Responses of Adults According to Cognitive Demand Levels for Horticultural Activities

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Abstract: We aimed to compare psychophysiological responses in adults according to cognitive demand levels for horticultural activities to confirm the feasibility of horticultural activity for improving attention and emotional states. A total of 60 adults in their 20s were included in this crossover design study. Participants performed soil-mixing activities with 2 cognitive demand levels for 2 min each. Electroencephalography (EEG) and electrocardiography (ECG) were performed during these activities. After each activity, the semantic differential method (SDM) was used to evaluate the emotional states of the participants. EEG results revealed that relative fast alpha and low beta power spectrums in the frontal lobes were high during the activity with high cognitive demand compared to those during the low demand activity, which indicates activation in the prefrontal cortex. ECG results showed that during the high cognitive demand activity, the standard deviation of the RR intervals of male adults was high, indicating a high-stress resistance ability of the autonomic nervous system. However, as a result of the SDM, there were no significant differences in emotional states according to the level of activity difficulty. Therefore, this study confirmed the possibility that the intervention of horticultural activities of an appropriate difficulty did not negatively affect subjective emotional changes and could have a positive effect on the improvement of attention levels and emotional stability in adults.

Keywords: electrocardiography; electroencephalogram; heart rate variability; horticultural intervention; semantic differential method; socio-horticulture

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1. Introduction

1.1. Effects of Human Contact with Nature

Urbanization of modern society is rapidly changing the living space of modern people from a nature-centered to an artificial-centered environment [1]. As a result, the reduction in contact with the natural environment can cause various environmental stresses to humans [2]. Contrarily, contact with nature improves the quality of life and provides social and psychological benefits, thereby accelerating stress recovery [3,4].

Ulrich [5] suggested that contact with nature could induce human psychological stability, fatigue reduction, and stress relief, whereas isolation from nature worsens psychological health by increasing human fatigue and stress [6]. The biophilia and Savanna hypotheses explain the instinctual human preferences for nature [7,8]. "Biophilia" is a compound word comprising "bio" meaning "nature" and "philia" meaning "loving", and it has been theorized that human genes contain factors that induce cravings for greenery [7]. The Savanna hypothesis theorizes that the human brain remains in somewhat of a primitive stage as humans have lived in a nature-centered way for a long time; therefore, it is difficult to grasp a rapidly changing environment, such as that of modern society. Moreover, humans instinctively prefer being in the presence of nature, such as trees and flowers [8].

Additionally, the Attention Restoration Theory states that the recovery environment restores psychological stability and attention [9], and exposure to the natural environment is effective in restoring attention [10]. As such, various theories about the positive effects of nature on humans are supported by the theoretical basis of the psychobiological and evolutionary aspects between humans and nature.

1.2. Cognitive Effects of Horticultural Activities

Interventional horticultural activities using plants can have a positive effect not only on cognitive aspects but also on overall mental health and quality of life. As a result of children performing 3 horticultural activities (flower arrangement, planting, and flower pressing) for 9 weeks (once a week), the experimental group showed improved attention and concentration, which are cognitive functions, after the program compared to the control group [11]. The older adults performed six horticultural activities, which were low-to-moderate exercise intensity (cleaning a garden plot, digging, fertilizing, raking, planting/transplanting, and watering) to make a garden, and brain nerve growth factors (brain-derived neurotrophic factor [BDNF], vascular endothelial growth factor, platelet-derived growth factor) related to memory and cognitive functions were analyzed [12]. Platelet-derived growth factor and BDNF levels were significantly higher, demonstrating the potential of horticultural activities in improving cognitive ability in older adults. A horticultural activity program (planting plants, cooking with plant materials, and crafting with plant materials) was conducted for older adults with moderate dementia thrice a week for 9 weeks [13]. The results showed that interaction, concentration, and activity participation improved after participating in horticultural activities compared to those before participation in horticultural activities, which means that horticultural intervention had a positive effect on the cognitive and psychosocial aspects of older adults with moderate dementia. However, these studies did not design horticultural activities by objectively analyzing the individual cognitive levels of the participants. To effectively improve cognitive abilities through interventional horticultural activities, it is necessary to measure the cognitive demand levels of the participants and adjust the cognitive difficulty of the activity accordingly. These studies could not explain the rationale for such cognitive effects of horticultural activities. Therefore, we collected quantitative and objective data on changes in attention and emotional state during horticultural activities by setting cognitive demand levels for horticultural activities to close the gap of knowledge.

1.3. Electroencephalogram-Based Cognitive Load Assessment

Accurate measurement and classification of the level of cognitive load required for working memory are important for identifying the appropriate level of cognitive demand [14]. The measurement of cognitive load helps maintain the optimal cognitive load in various environments and high work demands [15], and there are various methods for measuring the cognitive load. Previous studies have used methods such as heart rate variability (HRV) [16], electroencephalogram (EEG) [17], skin conductance [18], and pupil changes [19] as physiological methods of measuring cognitive load. Among them, EEG has traditionally been used to study cognitive brain processes [20] and is suitable for continuously measuring the degree of cognitive load [21]. EEG is an electrophysiological measure that records the electrical activity of the brain [22] and has been used in the study of cognitive functions, such as arousal and drowsiness, attention, cognitive load, memory and executive function, and human brain pathology [23–26]. Several studies have measured cognitive load using these EEG measurement methods. For an in-depth analysis of the cognitive task difficulty level (TDL) to assess the level of program comprehension, eight students were asked to solve nine Java tasks of various difficulty levels, and cognitive loads were determined from the EEG measurements [27]. As a result, there was a clear difference according to the TDL, and classification according to difficulty was possible [27]. In another study, to evaluate the cognitive workload during mental arithmetic, 16 students were asked to perform a mental arithmetic task with 5 difficulty levels, and, as a result, they were classified into 3 conditions: relaxation, low cognitive load, and high cognitive load [28]. Additionally, to infer the participants' cognitive workload during the intelligence test using EEG, 52 adults in their 20s were asked to perform a task of 36 problems of sequentially increasing difficulty [29]. As a result, reasonable prediction accuracy was obtained using EEG measurements, suggesting that the TDL can be used in many cases [29]. As such, the method using EEG can be considered suitable for measuring cognitive load and classifying the TDL.

This study was conducted to investigate the psychophysiological responses and emotional states of adults when performing horticultural activities according to two types of cognitive demand levels using an EEG-based measurement method. Therefore, the research question we posed was: what are the responses in EEG, HRV, and emotional states during participation in horticultural activities according to the cognitive demand levels? To assess the feasibility of this, we designed the present study to investigate the effects of horticultural activities according to the cognitive load level on attention levels and emotional states to provide basic psychophysiological data.

2. Materials and Methods

2.1. Research Participants

In total, 60 adults in their 20s (30 men and 30 women; average age: 25.2 ± 2.7 years) participated in this study. The inclusion criteria were as follows: no physical disability, no history of mental illness, no taking related drugs that could affect cognitive ability, and right-handed dominance [30]. For recruitment, a flyer about the study information was distributed to apartment complexes in Gwangjin-gu, Seoul, Korea.

The participants were asked to fast for 2 h before the experiment because ingredients, such as caffeine, which naturally occurs in various foods, could stimulate brain activity and affect the data [31]. The participants were also asked to complete a questionnaire including questions regarding their age, gender, height, weight, and body mass index (BMI) (ioi 353; Jawon Medical Co., Ltd., Gyeongsan, Korea). These were measured before the experiment.

The participants received an incentive (approximately USD 15) after completing the study. The Institutional Review Board of Konkuk University approved this study (7001355-201809-HR-271 and 7001355-201809-HR-268).

2.2. Experimental Condition

The study was conducted in a greenhouse at Konkuk University, Seoul, Korea. In a space for the experiment (200 × 160 cm), a white hardboard was attached to the wall across from the participant's face and an ivory-colored curtain was placed on both sides to minimize external stimuli (Figure 1).

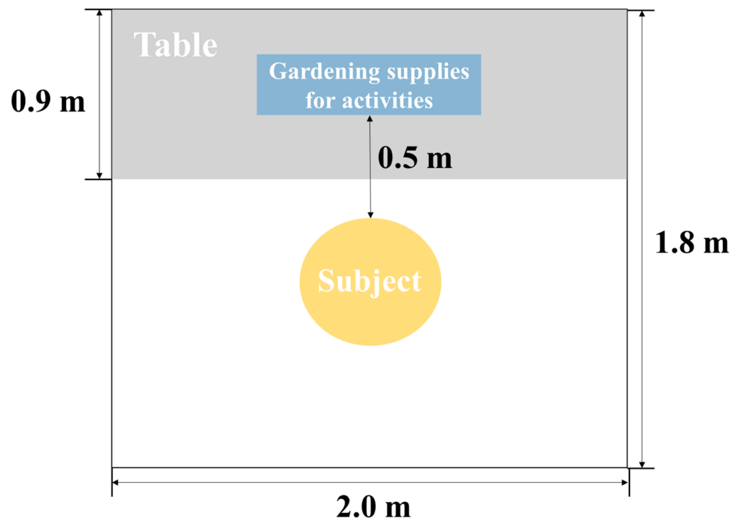


Figure 1. Room arrangement for the experiment.

To create a quiet space, external noise was blocked, and the average indoor temperature was set within the range of 23.0 to 26.0 °C according to the recommended temperature by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers [32]. The conditions of the space were as follows: average temperature, 24.62 ± 2.97 °C (O-257; DRETEC Co., Ltd., Saitama, Japan); average relative humidity, 27.94 ± 12.33% (O-257; DRETEC Co., Ltd.); and average illumination, 2019.68 ± 1322.32 lux (ST-126; SINCON, Bucheon, Korea).

2.3. Experimental Procedure

A crossover experimental study was conducted. Each participant performed the experimental protocol presented in Figure 2.

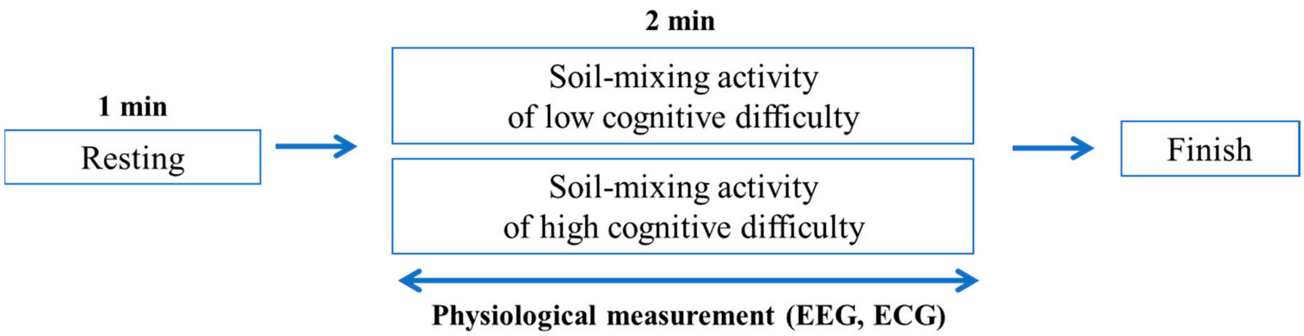


Figure 2. The experimental protocol. EEG, electroencephalography; ECG, electrocardiography.

Before starting the activity, each participant rested for 2 min on a white wall. The participants then performed 2 soil-mixing activities with different cognitive levels for 2 min (Table 1 and Figure 3). All participants received the same instructions and performed the activities in the same manner. The sequence of the two activities was randomized for each participant. The low cognitive load activity was performed by simply mixing the soil with both hands, and the high cognitive load activity was performed by measuring and mixing water and artificial soil according to the given instructions.

Table 1. Description of horticultural activities in this study.

Activity	Cognitive Demand Levels	Descriptions	Exercise Intensity (METs) [1]
Soil-mixing activity	Low level cognitive demand	Mixing pre-mixed soil (including peat moss, perlite, and water) in a basin evenly with both hands for 2 min.	3.6
	High level cognitive demand	Putting peat moss and perlite in an empty basin in a ratio of 7:3, pouring half of the water (300 mL) in a beaker, and mixing evenly with both hands for 2 min.	

[1] The exercise intensities of horticultural activity for adults in their 20s are referenced by Park et al. (2014) [33]. Metabolic equivalent of task (MET) represents the exercise intensity of physical activity in terms of oxygen consumption per unit of body mass (1 MET = 3.5 mL·O_2/kg/min) [34]. 3–6 METs are moderate intensity.

After conducting each activity for 2 min, we evaluated the emotional responses of the participants using the semantic differential method (SDM). Men and women participated in the experiment separately in random order.

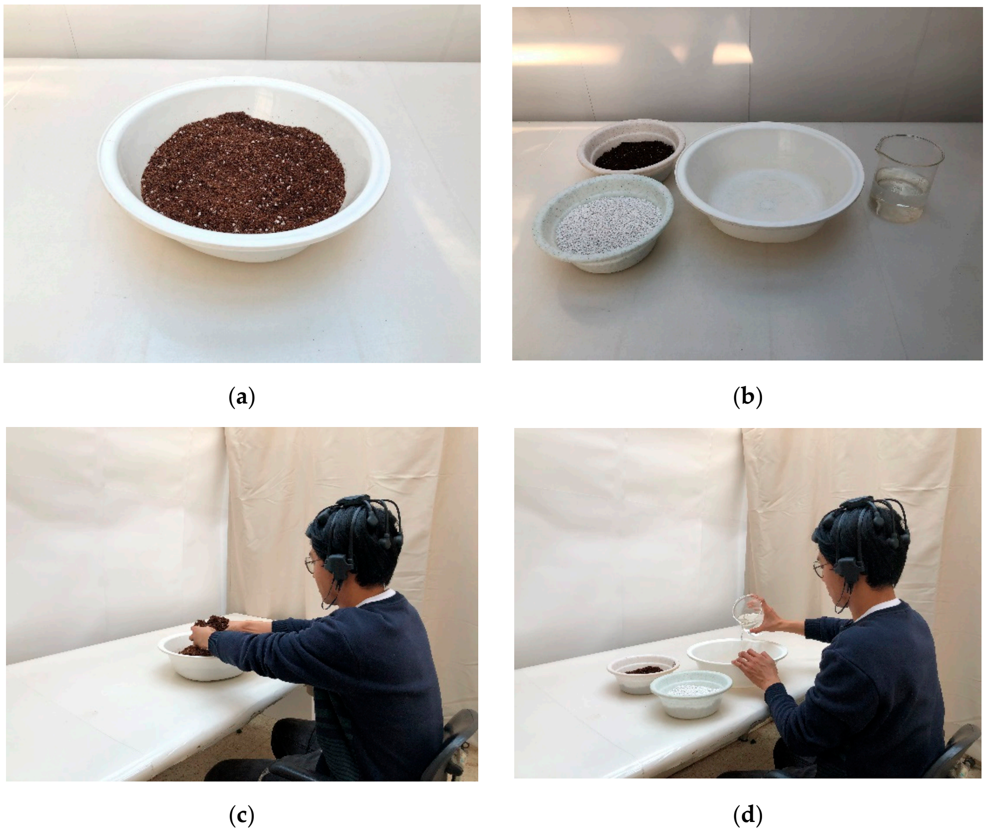


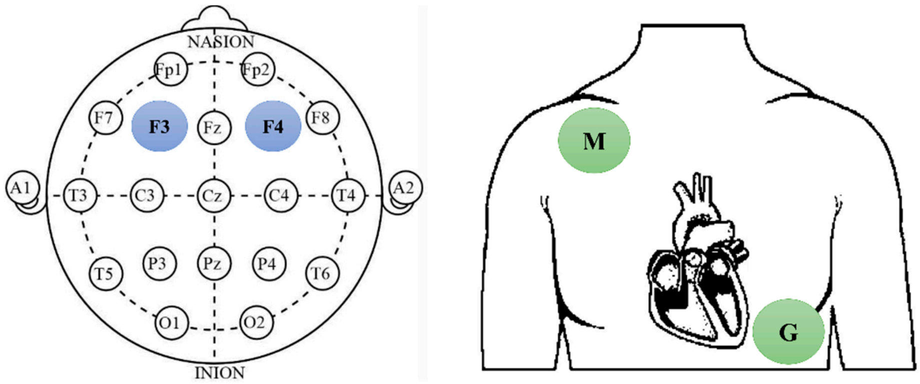
Figure 3. Experimental procedure. (**a**) Materials of soil-mixing activities of low cognitive difficulty; (**b**) materials of soil-mixing activities of high cognitive difficulty; (**c**) an adult participant performing soil-mixing activities of low cognitive difficulty; and (**d**) an adult participant performing soil-mixing activities of high cognitive difficulty.

As the experiment proceeded, participants were instructed to sit in a comfortable position with their chairs close to the center of the desk and not to make noise or speak. All experimental procedures were completed within approximately 30 min for all participants.

2.4. Measurement Items

2.4.1. Physiological Measurement

EEG and ECG were used as physiological measures. A wireless dry EEG device (Quick-20; Cognionics, San Diego, CA, USA) and a medical electrode (HP-OP42; Hurev, Wonju, Korea) were used to measure the brain activation and HRV of each participant according to the cognitive difficulty of the horticultural activity. The EEG device uses a dry electrode system, which minimizes the risk of electric shock and allows participants to quickly remove the electrode from the scalp if they feel uncomfortable. This device is widely utilized mainly in the field of neuroscience [35,36]. The device has a total of eight electrode channels following the international 10–20-electrode arrangement system (Figure 4a) [37]: the left prefrontal lobe (Fp1), right prefrontal 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). The EEG signal was collected at a sampling rate of 1 kHz.



(**a**) (**b**)

Figure 4. International electrode arrangement [36]. (**a**) The bolded channels (F3, F4) measured and (**b**) electrode of electrocardiography (ECG) lead placement (M, Measuring electrode; G, Ground electrode).

In this study, EEG monitoring was performed at the left frontal lobe (F3) and right frontal lobe (F4). The reference electrode was placed on the left ear clip (A1). The potential difference was determined by amplifying an electrical signal measured by contacting a dry electrode to the scalp and collecting the processed data. The prefrontal cortex is involved in cognitive control [38]. As for the method of wearing the device, the device was placed on the participant's head, checking the impedance on each pod. If required, sensors were adjusted for comfort and contact. The ECG electrodes were placed on the end of the collarbones, and ground electrodes were attached to the area of the left rib bones (Figure 4b).

2.4.2. Psychological Measurement

To measure the psychological reaction of participants according to the cognitive difficulty of the horticultural activity, we used the SDM [39]. The scale is a 13-point Likert scale consisting of 3 questions for "awakening-relaxed", "artificial-natural", and "uncomfortable-comfortable". Higher scores indicate a positive emotional state.

2.5. Data Processing and Analysis

We analyzed the collected EEG and ECG data using Cognionics Data Acquisition (Cognionics) and Telescan 2.2 software (Cognionics). The measured data were analyzed using the Bio-scan analysis program (Bio-Tech, Daejeon, Korea). Data were recorded through a built-in amplifier and digitized at 1 kHz (band pass 0.5 to 100 Hz). According to the frequency band (4 to 50 Hz), the EEG of both frontal cortexes was divided into 4 frequency bands: theta (4 to 8 Hz), alpha (8 to 13 Hz), beta (13 to 30 Hz), and gamma (30 to 50 Hz). Then, we analyzed the collected EEG data using power spectrum analysis to identify the relative low-beta (RLB) and fast-alpha (RFA) powers. We calculated and analyzed the RLB and RFA power spectra by the ratio of power in the 4 to 50 Hz band to power in the 12 to 15 Hz and 11 to 13 Hz, respectively [40]. We analyzed SEF50 as the frequency of the point on the power spectrum graph where the region from 4 to 50 Hz occupies 50% of the region in the entire frequency range [41]. We analyzed ASEF50 as the frequency of the point on the power spectrum graph where the region from 8 to 13 Hz occupies 50% of the region in the entire frequency range. These parameters are used to represent different states of the brain (Table 2).

Table 2. EEG parameters used in this study [42].

Analysis Indicator	The Full Name of the EEG Parameters	Indicator Estimate (Ratio)	State
RLB	Relative Low-Beta	Low-Beta (12–15 Hz)/ totalfrequency (4–50 Hz)	Attentive status
RFA	Relative Fast-Alpha	Fast-Alpha (11–13 Hz)/totalfrequency (4–50 Hz)	Relaxation and stabilization
SEF50	Spectral Edge Frequency 50% of Total Spectrum Band	The lowest frequency below which 50% of the total power in the total frequency band (4–50 Hz)	Awareness
ASEF50	Spectral Edge Frequency 50% of Alpha Spectrum Band	The lowest frequency below which 50% of the total power in the alpha frequency (8–13 Hz)	Adequate awareness withstability and relaxation

We analyzed the collected ECG data using Cognionics Data Acquisition (Cognionics). Raw ECG data were filtered and converted to HRV data. The HRV data (raw data) were analyzed using time- and frequency-domain analyses. The activity of the sympathetic and parasympathetic nervous systems was assessed by quantifying the RR interval, the interval between successive R peaks on ECG, and the rate of change in the RR interval [43]. The quantified HRV was analyzed by time-domain analysis to assess the standard deviation of NN intervals (SDNN). The quantified HRV was analyzed by frequency domain analysis to assess the following indicators: low frequency (LF) (0.04 to 0.15 Hz) and high frequency (HF) power (0.15 to 0.4 Hz). The SDNN reflects cardiovascular stability and the ability of the autonomic nervous system to maintain homeostasis and regulate the heart [44]. The LF and HRV are indicators of sympathetic and parasympathetic activity, respectively [45].

The results of EEG, ECG, and SDM for each activity were analyzed using an independent two-sample *t*-test performed using SPSS software (version 25 for Windows; IBM Corp., Armonk, NY, USA). All significance levels were set to $p < 0.05$. To analyze demographic information, Microsoft Excel (Office 2007; Microsoft Corp., Redmond, WA, USA) was used to determine the descriptive statistics such as means, standard deviations, and percentages.

3. Results

3.1. Demographic Information

Adults aged 25.2 ± 2.7 years participated in the study (30 men, 25.8 ± 2.4 years; 30 women, 24.5 ± 2.9 years) (Table 3). The overall average BMI was 23.0 ± 3.3 $kg{\cdot}m^{-2}$, which is within the normal range as per the criteria specified by the World Health Organization.

Table 3. Descriptive characteristics of participants who participated in the study.

Variable	Male (n = 30)	Female (n = 30)	Total (N = 60)	Significance [1]
	M ± SD			
Age (years)	25.8 ± 2.4	24.5 ± 2.9	25.2 ± 2.7	NS
Height [2] (cm)	176.3 ± 5.7	160.9 ± 6.1	168.7 ± 9.7	0.000 ***
Body weight [3] (kg)	76.2 ± 12.9	54.7 ± 8.5	65.6 ± 15.3	0.000 ***
Body mass index [4] ($kg{\cdot}m^{-2}$)	24.4 ± 3.6	21.6 ± 2.3	23.0 ± 3.3	0.001 **

[1] Statistical significance as determined using the independent two-sample *t*-test. **, *** significant at $p < 0.01$ or 0.001, respectively; NS, not significant. [2] Height was measured using an anthropometer (Ok7979; Samhwa, Seoul, Korea). [3] Body weight was measured using a body fat analyzer (ioi 353; Jawon Medical, Korea). [4] Body mass index was calculated using the formula: [weight (kg)]/[height (m)^2].

3.2. Electroencephalography (EEG)

When the participants performed the soil-mixing activity with high cognitive difficulty, the RLB index was significantly increased in the bilateral frontal lobes compared with the soil-mixing activity of low cognitive difficulty ($p < 0.05$; Table 4). The RFA index in the right frontal lobe was also significantly higher when performing the soil-mixing activity with high cognitive difficulty ($p < 0.05$).

Table 4. Results of the relative low-beta power spectra (RLB) and the relative fast-alpha power spectra (RFA) by electroencephalography (EEG) according to the activities.

Variable	Activity	RLB		RFA	
		F3	F4	F3	F4
		M ± SD			
Male (n = 30)	Low level cognitive demand	0.063 ± 0.016	0.066 ± 0.018	0.054 ± 0.015	0.056 ± 0.016
	High level cognitive demand	0.068 ± 0.020	0.072 ± 0.021	0.056 ± 0.018	0.061 ± 0.023
	Significance	0.716 NS	0.323 NS	0.443 NS	0.201 NS
Female (n = 30)	Low level cognitive demand	0.058 ± 0.012	0.060 ± 0.011	0.049 ± 0.012	0.052 ± 0.012
	High level cognitive demand	0.063 ± 0.019	0.065 ± 0.019	0.053 ± 0.017	0.057 ± 0.017
	Significance	0.002 **	0.003 **	0.033 *	0.023 *
Total (N = 60)	Low level cognitive demand	0.061 ± 0.014	0.063 ± 0.015	0.052 ± 0.014	0.054 ± 0.015
	High level cognitive demand	0.066 ± 0.019	0.068 ± 0.020	0.054 ± 0.018	0.059 ± 0.021
	Significance	0.025 *	0.016 *	0.052 NS	0.042 *

NS, non-significant; RFA, relative fast-alpha power spectra; RLB, relative low-beta power spectra; SMR, sensorimotor rhythm. *, ** significant at $p < 0.05$ and 0.01 by independent two-sample *t*-tests, respectively. RLB (SMR) was calculated as follows: (low-beta (12–15 Hz) power)/(total frequency (4–50 Hz) power). RFA was calculated as follows: (fast-alpha (11–13 Hz) power)/(total frequency (4–50 Hz) power).

The analysis between genders revealed no significant EEG changes according to the activity difficulty level in men, and the RLB and RFA indices of the bilateral frontal lobes were significantly higher in women when performing a high-difficulty activity ($p < 0.05$). As a result of the analysis of spectral edge frequency, the ASEF50 index significantly increased in the bilateral frontal lobes of women during the high-difficulty activity (Table 5; $p < 0.05$). The SEF50 showed no significant differences between the activities ($p > 0.05$).

Table 5. Results of spectral edge frequency of 50% (SEF50) and spectral edge frequency of 50% of alpha spectrum band (ASEF50) by electroencephalography (EEG) according to activity.

Variable	Activity	SEF50		ASEF50	
		F3	F4	F3	F4
		M ± SD			
Male (n = 30)	Low level cognitive demand	12.271 ± 5.734	10.992 ± 4.559	9.986 ± 0.382	9.974 ± 0.372
	High level cognitive demand	12.121 ± 6.125	10.827 ± 3.468	10.094 ± 0.414	10.075 ± 0.387
	Significance	0.583 NS	0.479 NS	0.353 NS	0.476 NS
Female (n = 30)	Low level cognitive demand	10.023 ± 4.710	9.366 ± 2.429	9.913 ± 0.264	9.899 ± 0.269
	High level cognitive demand	11.289 ± 5.905	9.455 ± 3.424	10.059 ± 0.353	10.038 ± 0.342
	Significance	0.336 NS	0.300 NS	0.045 *	0.040 *
Total (N = 60)	Low level cognitive demand	11.147 ± 5.325	10.179 ± 3.713	9.949 ± 0.328	9.937 ± 0.324
	High level cognitive demand	11.705 ± 5.980	10.141 ± 3.486	10.077 ± 0.382	10.057 ± 0.363
	Significance	0.323 NS	0.971 NS	0.050 NS	0.082 NS

ASEF50, spectral edge frequency of 50% of alpha spectrum band (8 Hz to 13 Hz); NS, non-significant; SEF50, spectral edge frequency of 50%; * significant at $p < 0.05$ by independent two-sample *t*-tests, respectively.

3.3. Electrocardiography (ECG)

The ECG results showed that the SDNN was significantly increased in men for the high-difficulty activity (Table 6; $p < 0.05$); there was no significant difference between women and all participants ($p > 0.05$). The heart rate, LF, and HF showed no significant differences among activities in all participants ($p > 0.05$).

Table 6. Results of heart rate variability (HRV) according to activity.

Variable	Activity	Heart Rate	LF	HF	SDNN
		M ± SD			
Male (n = 30)	Low level cognitive demand	84.88 ± 9.25	0.71 ± 0.14	0.29 ± 0.14	34.68 ± 9.81
	High level cognitive demand	83.72 ± 9.56	0.73 ± 0.14	0.27 ± 0.14	41.60 ± 15.62
	Significance	0.969 NS	0.590 NS	0.590 NS	0.028 *
Female (n = 30)	Low level cognitive demand	84.38 ± 9.76	0.66 ± 0.19	0.34 ± 0.19	36.23 ± 12.60
	High level cognitive demand	84.77 ± 8.93	0.72 ± 0.15	0.28 ± 0.15	39.50 ± 26.59
	Significance	0.522 NS	0.070 NS	0.070 NS	0.293 NS
Total (N = 60)	Low level cognitive demand	84.63 ± 9.43	0.68 ± 0.17	0.32 ± 0.17	35.45 ± 11.22
	High level cognitive demand	84.25 ± 9.19	0.73 ± 0.15	0.27 ± 0.15	40.55 ± 21.65
	Significance	0.690 NS	0.102 NS	0.102 NS	0.057 NS

HF, high frequency; LF, low frequency; NS, non-significant; SDNN, standard deviation of NN intervals. * significant at $p < 0.05$ by independent two-sample t-tests, respectively. LF was calculated as (low frequency band (0.04–0.15 Hz))/(total frequency band (0.04–0.4 Hz)). HF was calculated as (low frequency band (0.15–0.4 Hz))/(total frequency band (0.04–0.4 Hz)). SDNN was standard deviation of RR intervals.

3.4. Semantic Differential Method (SDM)

The SDM results showed no significant differences in physiological feelings with regard to activity difficulty (Figure 5; $p > 0.05$). Similar to the results obtained based on sex difference, there was no significant difference in SDM results based on activity difficulty ($p > 0.05$).

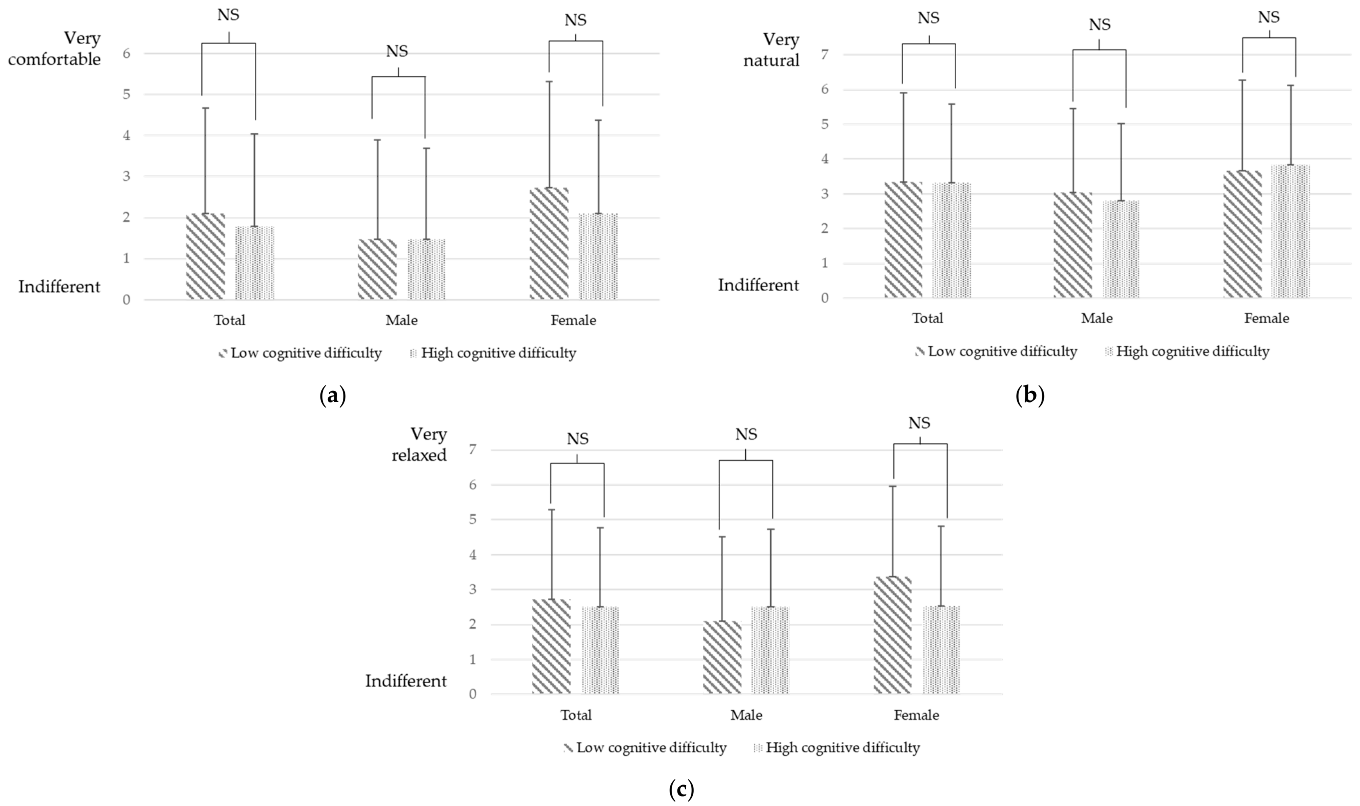


Figure 5. Comparison of a semantic differential method (SDM) according to activity. (**a**) Being comfortable, (**b**) being natural, and (**c**) being relaxed. NS, non-significant.

4. Discussion

This study investigated psychophysiological responses in adults according to their levels of cognitive demand for horticultural activities. EEG and ECG monitoring were performed to compare the activation in the prefrontal cortex and autonomic nervous system in adults who performed horticultural activities according to the levels of cognitive demand. Additionally, we used the SDM to compare emotional conditions according to activity difficulty. The EEG results revealed that RFA, RLB, and ASEF50 in the frontal lobes were higher during the high cognitive demand activity compared to the low demand activity (Tables 4 and 5; $p < 0.05$). The results of the ECG showed that the SDNN was higher during high level cognitive demands for the soil-mixing activity (Table 6; $p < 0.05$). There was no significant difference in SDM according to activity difficulty (Figure 5).

By measuring the electrical activity of the brain, EEG can associate different frequencies with different types of brain activities [46]. In general, these are divided into delta, theta, alpha, beta, and gamma according to the frequency band and reflect different functional roles [47]. The frontal lobe is a brain lobe located anterior to the cerebral hemispheres and plays an important role in various cognitive processes, such as attention, memory, and language [48]. In this study, we parameterized into four indicators: RLB index (low-beta (12–15 Hz) power)/(total frequency (4–50 Hz) power); RFA index (fast-alpha (11–13 Hz) power)/(total frequency (4–50 Hz) power); SEF50 (the lowest frequency below which 50% of the total power in the total frequency band (4–50 Hz)); ASEF50 (the lowest frequency below which 50% of the total power in the alpha frequency (8–13 Hz). The RLB index is activated in an attentive status and works in a relaxed state and a stress-free state of concentration [49]. The RFA index is mainly activated when emotional anxiety is stable and the brain is awake [40]. The SEF50 is an indicator of arousal state and cognitive load on the brain that shows how much of the brain is active during a task [50]. The ASEF50 is an index for adequate awareness with stability and relaxation [42].

When the participants performed the soil mixing activity with high cognitive difficulty, the RLB index significantly increased in the bilateral frontal lobes compared with the soil mixing activity with low cognitive difficulty ($p < 0.05$; Table 4). The beta band represents EEG activity in the range of 13–30 Hz and occurs during mental activity, problem-solving, and deep concentration [51,52]. Beta waves are subdivided into RLB (12–15 Hz), relative mid beta (15–20 Hz), and relative high beta (20–30 Hz), and when activated, they improve concentration and attention [53,54]. According to previous studies, an increase in beta bands is associated with improvements in cognitive functions such as memory function, language function, and attention [55]. An increase in the beta bands may help improve or maintain cognitive function [46]. Therefore, the increased RLB index indicates increased attention and concentration of the participants in this study [56].

In addition, the RFA index was higher in the right frontal lobe when performing soil-mixing activities with high cognitive difficulty ($p < 0.05$). Alpha band occurs at a frequency of 8–13 Hz and represents a relaxed state of arousal [45,51]. An increase in RFA and ASEF means that the ratio of fast-alpha waves in the whole brain wave increases, and when fast-alpha waves increase, it awakens the brain and improves cognitive ability while providing a state of stability and comfort [57]. This means that the horticultural activity of high cognitive difficulty had a positive effect on the prefrontal cortex activity of the participants and that they experienced a high cognitive load compared to the low cognitive difficulty activity.

The results of this study revealed differences, by gender, in the EEG changes of participants performing soil-mixing activities. In men, there were no EEG changes according to activity level; however, in women, the RLB, RFA, and ASEF50 indices of the bilateral frontal lobes were significantly higher when performing activities with high cognitive difficulty ($p < 0.05$; Tables 4 and 5). These differences between males and females can be explained by structural and functional differences in the brain [58] and morphological, neurochemical, and neurophysiological factors of sex dysmorphism in hemispheric interactions [59–62]. Additionally, we found that there were sex-specific EEG changes when performing cognitive function tasks, such as concentration and creative thinking, similar to previous studies [63]. Although it is not possible to draw anatomical, origin, or functional conclusions about the observed gender differences due to the nature of this study, the results of previous studies that showed differences in EEG according to gender when performing cognitive tasks, such as divergent thinking [63], intensive assignment [30], and spatial and analytical tasks, support the results of this study [64].

HRV reflects changes over time using heart rate and the interval between beats, which controls heart activity, and the SDNN (or RR interval) obtained from the electrocardiogram [65]. A higher SDNN means that a lower level of mental effort is required [66], and a lower SDNN relates to higher degrees of emotional sensitivity and stress susceptibility [67]. The ECG analysis in this study showed that the SDNN in men was higher in the high level cognitive demand compared with the low level cognitive demand soil-mixing activity (Table 6; $p < 0.05$). In other words, men are in a state of physiological stability when they engage in high cognitive demand activities.

SDM was performed to investigate the emotional state of participants following each activity. There was no significant difference in SDM among participants according to activity level (Figure 5). This means that there was no significant difference in psychological emotions among participants when the cognitive demand for the activity was high and when the cognitive demand for the activity was low. This means that the high cognitive difficulty horticultural activity performed in this study had a high cognitive demand as it affected the prefrontal cortex activity of the participants, although it did not negatively affect the subjective psychological states.

The reconnection between humans and nature can lead to the recovery of cognitive functions such as memory, attention, and concentration [42]. Several previous studies have been conducted on this topic. When performing a task (arithmetic problem) for elementary school students, concentration improved in an environment with plants compared with an environment without plants [30]. When 11 horticultural activities were performed by adults, brain activity increased and concentration improved [68]. As a result of the horticultural activities, cognitive function and mental health improved in mothers less than one year postpartum [69]. The result of the horticultural activity program for the elderly with mild to moderate dementia was that the Vitality Index and Mini-Mental State Examination scores improved significantly after the horticultural activity program was implemented compared with before the program [70]. In a similar study, horticultural activities such as seed sowing and plant planting had a positive effect on cognitive function and emotional stability by activating the brains of elderly participants compared with general leisure activities [55].

Previous studies have investigated the effects of horticultural activities on cognitive function. On the other hand, in this study, the difficulty of horticultural activities was classified according to the level of cognitive demand, and the effect of horticultural activities according to the level of difficulty on the prefrontal cortex activity and emotional states of the participants was investigated. According to the results of this study, it can be seen that activities with high cognitive demands are more effective for increasing concentration and attention levels than activities with low cognitive demands in adults. However, because only one horticultural activity was performed in this study, it is unclear whether the same effect would be observed with all horticultural activities. This study was derived from a controlled study designed to investigate the psychophysiological characteristics of each soil-mixing activity for 2 min. It is different from the actual horticultural activities' performance environment, and since only one type of horticultural activity was investigated, it is also necessary to investigate various types of horticultural activity. In addition, because the participants were limited to adults in their 20s, the results of this study cannot be generalized to other age groups. Therefore, further research is needed to expand the scope of this study to investigate the effects of horticultural activities on the cognitive function of participants according to various horticultural activities and cognitive demand levels in various age groups.

5. Conclusions

The aim of this study was to measure the effects of horticultural activities on the psychophysiological responses of adults according to the level of cognitive demand. As a result, when the cognitive demand level of a horticultural activity was high, activity in the prefrontal cortex of the participants significantly improved, possibly indicating improvements in attention. This study explains why horticultural activities should be classified according to individual cognitive demand levels. In addition, it is necessary to identify the cognitive and emotional benefits of horticultural activities of various cognitive demand levels using evaluation tools that evaluate cognitive function and mental health in actual clinical practice to generalize the feasibility observed in this study. The results could be used to develop horticultural programs for maintaining or improving cognitive health.

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