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Effects of Cognitive Demand Levels for Various Horticultural Activities on Psychophysiological Responses in Adults

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Keywords. cognitive load, electrocardiography, electroencephalogram, gardening, heart rate variability, horticulture activity, semantic differential method

Abstract. **We compared the effects of horticultural activities according to cognitive demand levels on psychophysiological responses in adults. Thirty-two adults in their 20s were included. Participants performed 10 horticultural activities (raking, planting transplants, fertilizing, tying plants to stakes, harvesting, sowing, conducting cuttage, planting potted plants, cutting and washing, arranging flowers) for 150 seconds at two levels of cognitive demand. Electroencephalographic (EEG) and electrocardiographic measurements were acquired during the activity. After each activity, the participants' emotional states were evaluated using the semantic differential method (SDM). The EEG results, according to comparison by activity, showed that for nine activities, excluding raking, relative theta decreased when performing tasks at a level of high cognitive difficulty (HCD) compared with those with a low cognitive difficulty (LCD), and relative beta, relative gamma, fast alpha, and relative low beta increased, indicating activation of the prefrontal cortex. In the relative theta power spectra, the cuttage activity was found to be the lowest when performing tasks at a high level high cognitive difficulty, and the working memory function was activated the most compared with other activities. When sowing at a low level of cognitive demand, participants' heart rate decreased and stabilized. When potted plants were harvested at a high level of cognitive difficulty, the ratio of low frequency to high frequency increased, and the sympathetic nervous system was activated. In addition, when planting transplants, and cutting and washing were performed at a high level of cognitive difficulty, and the standard deviation of the RR interval was high, indicating a high ability of the autonomic nervous system to resist stress. As a result of the SDM, the emotional state according to task difficulty was found to be more stable and relaxed than high cognitive difficulty, but a significant increase in comfort, relaxation, and naturalness was achieved when nine gardening tasks with low cognitive difficulty were performed, with the exception of sowing. The results of this study show that tasks with high cognitive difficulty activate working memory, whereas those with low cognitive difficulty stabilize and relax brain activation. Therefore, this study confirmed that an intervention in horticultural activities with an appropriate level of cognitive difficulty could have a significant effect on psychophysiological changes in adults.**

Urbanization in modern society has forced more than half of the world's population to live in urban areas (Ohly et al. 2016), leading to a disconnect between humans and nature. This reduced contact with the natural environment exposes humans to various environmental stressors (Stilgoe 2001). According to the attention restoration theory, modern urban lifestyles increase demands on cognitive resources, and intensified demands induce a state of attentional fatigue (Kaplan 1995; Kaplan and Berman 2010). In contrast, contact with nature has a positive effect on overall well-being, including a positive impact on psychological and mental health (Chiesura 2004; Hung and Chang 2021). In addition, reconnection between humans and nature can lead to the recovery of cognitive functions, such as memory, attention, and concentration, and can increase sustainability (Ives et al. 2018; Lee et al. 2021).

In modern life, horticulture is a representative activity in which people interact easily and intimately with nature. It includes a variety of plant-based activities, such as planting plants, arranging flowers, and appreciating natural landscapes, and it provides opportunities to interact with living organisms, such as animals (Chen et al. 2013). Horticultural therapy is an activity that improves or maintains the functions of the human mind and body through plants or horticultural activities and is used as a nondrug interventional treatment. Horticultural therapy induces curiosity and improves judgment and coping skills. The repetition of these experiences leads to increased knowledge and skills training, thus improving self-esteem (Kang and Kang 2021). In addition, by observing plants, creativity and self-expression can be developed to show emotional effects (Kang and Kang 2021; Whear et al. 2014). By providing opportunities for social interaction, students can learn how to cooperate, divide labor, and communicate effectively (Whear et al. 2014). Interventional horticultural treatment using plant activities provides health benefits in terms of physical, psychological, emotional, and cognitive aspects, and can have a positive impact on quality of life (Park et al. 2016, 2017, 2020).

Many studies have been conducted to demonstrate the effects of horticultural activities and therapies. In terms of physical aspects, energy consumption was measured to determine the exercise intensity of gardening activities (Park et al. 2011, 2013, 2014), and muscle activity was measured to investigate the muscles activated according to gardening activities (Park et al. 2013, 2014). In addition, motion analysis was conducted to identify kinematic factors, such as joint angles and gripping patterns, according to gardening activities (Lee et al. 2016, 2018). Regarding psychoemotional aspects, brain waves were measured by electroencephalography during gardening activities, and it was found that attentional concentration improved (Kim et al. 2020, 2021). When examining plants using near-infrared spectroscopy, the concentration of oxygen-hemoglobin was found to be reduced significantly, which had a positive effect on psychological relaxation (Oh et al. 2019; Park et al. 2017). In addition, there is a difference in the degree of interest and emotional change according to the type of flower when arranging flowers (Wu et al. 2022). In terms of cognition, brain-derived neurotrophic factor levels increased significantly after attending gardening programs and performing gardening activities, suggesting there is potential for cognitive improvement (Park et al. 2020). In addition, when soil mixing was performed at a high level of cognitive demand, the activity in the prefrontal cortex (PFC) increased significantly (Kim et al. 2022). Studies on the physical and psychoemotional aspects of horticultural activities are being actively conducted, whereas studies on the cognitive aspects are insufficient.

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Therefore, we investigated the effects of various horticultural activities according to cognitive demand levels by extending the study by Kim et al. (2022).

Cognitive load refers to the amount of cognitive demand required for working memory when performing mental tasks such as learning or problem solving (Mazher et al. 2017; Sweller 1994). Effective learning can occur when cognitive demands match working memory (Rebsamen et al. 2011). Working memory is a brain function that stores and provides temporarily information necessary for cognitive tasks such as language comprehension, learning, and reasoning (Backs and Walrath 1992), but there are limitations in capacity and time when storing or processing information (Fuentes-Garcia et al. 2019; Sweller 2011). Therefore, when the amount of information to be processed exceeds the amount of information that can be processed, the accessibility of working memory decreases, and the cognitive load increases, resulting in cognitive overload (Mazher et al. 2017; Paas et al. 2003). Thus, the working memory structure and its limitations must be considered when performing cognitive working memory assessments (Mazher et al. 2017).

Cognitive load theory considers cognitive overload to be a major cause of poor learning (Sweller 1994). The purpose of this study is to identify the causes of unnecessary cognitive load, induce effective learning, and develop learning strategies (Sweller 1994). To achieve effective learning, an appropriate level of cognition is required according to the subject. To identify this, it is necessary to measure the degree of cognitive load during the learning process. Measuring cognitive load helps to maintain an optimal cognitive load in a variety of environments and while conducting tasks with a level of high cognitive demand (Faller et al. 2019).

To identify the appropriate level of cognitive demand, it is important to measure and classify accurately the cognitive load required for working memory to identify an appropriate level of cognitive demand (Paas et al. 2003). There are various methods for measuring cognitive load. Previous studies have used methods such as heart rate variability (HRV) (Mazher et al. 2017), brain waves (electroencephalography) (Antonenko et al. 2010), skin conductance (Niedermeyer and da Silva 2005), and pupil changes (Gale and Edwards 1983) as physiological methods to measure cognitive load. Among these, electroencephalography has been used traditionally to study brain cognitive processes (Zarjam et al. 2011) and is a suitable tool for measuring the degree of cognitive load continuously (Chandler and Sweller 1991). In our study, electroencephalography and electrocardiography were measured, and the semantic differential method (SDM) was used to investigate their effects on the psychophysiological response and emotional state of adults in terms of cognitive aspects when performing various horticultural activities according to the level of cognitive demand.

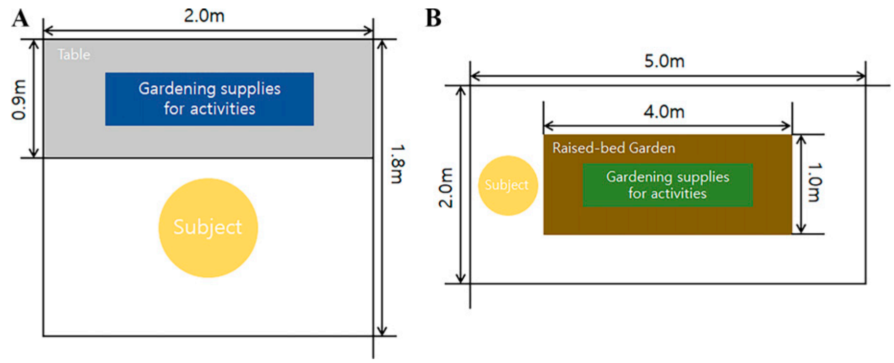

Fig. 1. Experimental space layout. (**A**) Indoor experimental space. (**B**) Outdoor experimental space.

Materials and Methods

Research participants

This study included 32 adults in their 20s (16 men and 16 women; average age, 23.2 ± 3.0 years). Participants were recruited using convenience sampling. Leaflets containing research information were distributed to schools, apartments, and libraries in Gwangjin-gu, Seoul, for recruitment. The inclusion criteria were as follows: no physical disability, no history of mental illness, no use of drugs that could affect cognitive ability, and right-hand dominance. Participants were asked to fast for 3 h before the experiment to prevent substances such as caffeine from stimulating brain activity and affecting the data (Heckman et al. 2010). Before conducting the study, the participants were informed of the contents of the study and precautions, and they then provided written consent. Age, gender, height, weight, and body mass index (ioi 353; Jawon Medical Co., Ltd., Gyeongsan, Korea) were recorded to collect demographic information. Participants visited the greenhouse three times during the experiment. After the experiment was completed, an incentive (∼US $50) was received. This study was approved by the Bioethics Committee of Konkuk University (7001355-202203-HR-519, March 2022).

Experimental conditions

This study was conducted in a greenhouse at Konkuk University in Seoul, Korea. Indoor horticulture activities were conducted inside a greenhouse (200 × 160 cm) (Fig. 1A). The environmental conditions of the experimental space were an average temperature of 24.3 ± 2.5 °C (O-257; DRETEC Co., Ltd., Saitama, Japan), with an average relative humidity of 23.7 ± 10.3% (O-257; DRETEC Co., Ltd.). The average illuminance was 9846.7 ± 2683.6 lux (ST-126; SINCON, Bucheon, Korea). Outdoor horticultural activities were carried out on a vegetable garden bed installed outside the greenhouse and were conducted in a space dedicated to the experiments (500 × 200 cm) (Fig. 1B). The environmental conditions of the experimental space included an average temperature of 20.6 ± 3.3 °C (O-257; DRETEC Co., Ltd.), an average relative humidity of 19.8 ± 6.3% (O-257; DRETEC Co., Ltd.), and an average illuminance of 18,717.5 ± 9191.6 lux (ST-126, SINCON).

Experimental procedure

Each participant followed the experimental protocol shown in Fig. 2. In this study, 10 types of horticultural activities were performed, and each horticultural activity was divided into two cognitive demand levels. Tasks with low cognitive difficulty consisted of simple activities with relatively few steps, whereas tasks performed at level of high cognitive difficulty consisted of complex activities with many steps. Three to four horticultural activities were performed per visit. Before starting the activity, each participant rested for 120 s. The participants then performed each horticultural activity for 150 s at two different cognitive

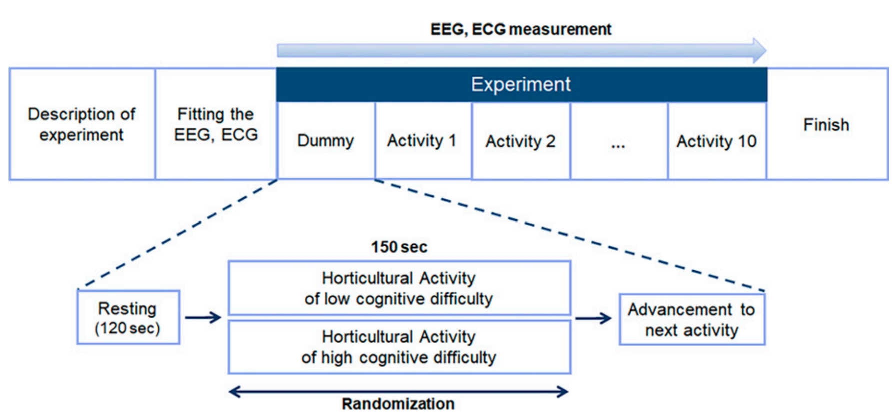

Fig. 2. Study procedure at each visit. EEG = electroencephalogram or electroencephalographic; ECG = electrocardiogram or electrocardiographic.

demand levels. All participants received the same instructions and performed the activities in the same manner. The order of activities was assigned randomly to each participant.

The 10 horticultural activities used in this study were selected through consultation with five experts active in the field of horticultural therapy, and a manual was prepared to enable the tasks to be performed within the activity time (Table 1). The 10 horticultural activities were divided into indoor and outdoor activities. Indoor horticulture consisted of five activities: sowing, performing cuttage, planting potted plants, cutting and washing, and arranging flowers. Outdoor horticulture consisted of five activities: raking, planting transplants, fertilizing, tying plants to stakes, and harvesting. The selected horticultural activities are used frequently in horticultural therapy and gardening. Each task presented in the horticulture activity manual involved different levels of cognitive demand.

When raking at a low level of cognitive difficulty, one grasps the rake, lifts it to head height, sticks it into the ground, and plows. When performed at a higher cognitive demand, in addition to the previous steps, one finds foreign objects and collects them. Planting transplants at a low level of cognitive difficulty entails digging the ground, planting seedlings such as lettuce, and covering them soil. At a higher level of cognitive demand, planting intervals are considered, locations are determined, and various seedlings are planted. Fertilizing at a low level of cognitive demand involves picking up solid fertilizer and spraying it around plants; at a higher level of cognitive demand one prepares and sprays liquid fertilizer onto the leaves. Tying plants to stakes at a low level of cognitive difficulty involves holding and fixing; at a high level of cognitive demand one must insert a support pole into the ground, then tie plants to it using a specific method. Harvesting lettuce leaves from a vegetable garden box involves a low cognitive demand; at a high level, specific lettuce varieties are chosen. Sowing at a low cognitive demand includes making holes, planting seeds, and covering them. At a high level of cognitive difficulty, lettuce seeds are prepared, absorbed, and placed carefully. Cuttage at a low level of cognitive demand entails separating and inserting cuttings; at high level, tree branches are pruned, leaves are trimmed, and growth promoter is applied. Planting potted plants at a low level of cognitive difficulty requires one to prepare pots and transfer plants; at a high level, additional steps such as determining soil type and isolating plants are added. The cutting and washing activity involves washing lettuce leaves at a low level of cognitive demand; at a high level, one must also remove wilted leaves and stems, and arrange them by size. Arranging flowers involves inserting trimmed flowers into foam (low cognitive demand), whereas at a high level of cognitive difficulty, flowers are prepared further, woven, and arranged creatively. These activities highlight the nuanced skills and considerations involved in different facets of horticultural practice.

Electroencephalography of the PFC was conducted during each activity. Then, after performing the activity for 150 s, the participants' emotional responses were evaluated using the SDM. During the experiment, the participants were instructed not to make any noise or speak. All experimental procedures were performed over three visits, and each visit took an average of 70 min.

Measurement items

Physiological measurement. Electroencephalography and electrocardiography were used for the physiological measurements. Electroencephalography is a noninvasive method for recording electrophysiological signals generated in the human brain (Lina and Karwowski 2020) and is widely used in the field of neuroscience (e.g., to evaluate motor function, cognitive load, attention level, and brain disorders) (Maddirala and Veluvolu 2021). In addition, it has been used traditionally to study cognitive processes (Fuentes-Garcia et al. 2019) and is a suitable tool for measuring the degree of cognitive load continuously (Antonenko et al. 2010). In our study, participants' brain activity and HRV were measured using a wireless electroencephalographic (EEG) measuring device (Quick-20; Cognionics, San Diego, CA, USA) and medical electrodes (HP-OP42; Hurev, Wonju, Korea), in relation to the cognitive difficulty of the gardening activities. The EEG measurement device used in this study minimized the risk of electric shock using a dry electrode system.

We performed EEG monitoring on the left and right prefrontal lobes according to the international 10–20 electrode array system (Jasper 1958; Klem et al. 1999) (Fig. 3A). Data were collected by amplifying the electrical signals measured by contacting the scalp with dry electrodes. The EEG signals were collected at a sampling rate of 1 kHz. A reference electrode was placed on the left ear clip (Fig. 3B). The electrocardiographic (ECG) electrode was placed at the end of the clavicle, and the ground electrode was attached to the left rib area (Fig. 3B). This device has been certified by the European Commission and the Federal Communications Commission (Kim et al. 2020).

Psychological measurement. The SDM was used as a physiological measure (Osgood et al. 1957) to examine participants' psychological responses to the cognitive difficulties of gardening activities. The scale is a 13-point Likert scale that consists of three options: comfortable/uncomfortable, relaxed/awake, and natural/artificial. The higher the value of each item, the more positive the emotional state.

Data processing and analysis

The measured EEG data were analyzed using the Bio-scan analysis program (Bio-Tech, Daejeon, Korea). Data were collected at a speed of 1 kHz (bandpass, 0.5–100 Hz) using a brain mapping program (Bioteck Analysis Software, Daejeon) through the built-in amplifier. The collected EEG data were analyzed for five power spectra: relative theta (RT), relative beta (RB), relative gamma (RG), relative low beta (RLB), and relative fast alpha (RFA). Each indicator was analyzed according to the following criteria (Kim et al. 2022; Klink et al. 2020). The RT power spectrum was calculated and analyzed using the ratio of power in the 4- to 50-Hz band to power in the 4- to 8-Hz band, revealing cognitive and working memory status. Similarly, the RB power spectrum was calculated and analyzed using the ratio of power in the 4- to 50-Hz band to power in the 13- to 30-Hz band, indicating attentive status. The RG power spectrum was calculated and analyzed using the ratio of power in the 4- to 50-Hz band to power in the 30- to 50-Hz band, revealing cognitive and attentive status. For the RFA power spectrum, the ratio of power in the 4- to 50-Hz band to the power in the 11- to 13-Hz band was calculated and analyzed, demonstrating relaxation and stabilization. Last, the RLB power spectrum was calculated and analyzed using the ratio of power in the 4- to 50-Hz band to power in the 12- to 15-Hz band, indicating attentive status. These parameters represent the physiological state of the brain.

Results

Demographic characteristics

Adults age 23.2 ± 3.0 years participated in the study (16 men, 24.9 ± 3.3 years; 16 women, 21.6 ± 1.5 years) (Table 2). The average height was 166.4 ± 7.9 cm. The average body weight was 61.8 ± 10.0 kg. The overall average body mass index was 22.4 ± 3.4 $kg \cdot m^{-2}$, which is within the normal range per the criteria specified by the World Health Organization.

Electroencephalography

Comparison by activity. EEG analysis of 10 horticultural activities according to cognitive difficulties showed that cognition and attention were activated in the same frequency band as RT and RG according to the cognitive difficulties of nine horticultural activities, with the exception of raking ($P < 0.05$) (Table 3). Planting, and cutting and washing resulted in increased RFA and RLB markers in the bilateral PFC when performing tasks at a high level of cognitive difficulty ($P < 0.05$). With regard to the fertilizing activity, RG was found to increase in the PFC when performing tasks with a low level of high cognitive difficulty ($P < 0.01$), whereas RFA and RLB indicators were found to decrease ($P < 0.05$). Tying plants to stakes showed that RG increased in the left PFC when performing tasks with high cognitive difficulty ($P < 0.01$), and the RLB index decreased in the bilateral PFC ($P < 0.05$). Harvesting showed that the RLB index increased in the left PFC when performing tasks with a high level of cognitive difficulty ($P < 0.05$). Sowing found that RB and RG indicators increased in the PFC when performing tasks at a level high of cognitive difficulty ($P < 0.01$), whereas RT indicators decreased ($P < 0.01$). With regard to performing cuttage, RB, RG, and RFA indicators increased ($P < 0.05$), and RT indicators decreased ($P < 0.001$) in the bilateral PFC when performing tasks at a high level of

Table 1. Horticulture activity manual.

Activity	Cognitive demand level	Description
Raking	Low	1. Grab a rake. 2. Place weight on your left foot and lift the rake to head height. 3. Bend forward and stick the rake into the ground. 4. Pull the rake toward you to plow the ground.
	High	1. Grab a rake. 2. Place weight on your left foot and lift the rake to head height. 3. Bend forward and stick the rake into the ground. 4. Pull the rake toward you to plow the ground. 5. Find foreign objects, such as stones. 6. Pick up the foreign objects and put them in a basket.
Planting transplants	Low	1. Use a trowel to dig a hole in the ground to a depth of 10 cm at the designated location. 2. Plant the lettuce seedlings. 3. Cover the ground with surrounding soil.
	High	1. Ascertain the planting interval for the three types of seedlings. 2. Decide where to plant the seedlings. 3. Use a trowel to dig a hole in the ground to a depth of 10 cm at the designated location. 4. Plant the lettuce, pepper, and pumpkin seedlings. 5. Cover the ground with surrounding soil.
Fertilizing	Low	1. Pick up the basket of solid fertilizer. 2. Spray a small amount of solid fertilizer on the soil around the pepper plant.
	High	1. Make liquid fertilizer by weighing water and liquid fertilizer stock solution according to the indicated ratio. 2. Transfer the liquid fertilizer made into a sprayer. 3. Grab the plant leaves. 4. Spray the liquid fertilizer onto the plant leaves.
Tying plants to stakes	Low	1. Hold the O-ring support. 2. Affix the plant stem to the O-ring support.
	High	1. Grasp the rod support. 2. Plant pole supports 15 to 20 cm deep, 5 cm to the side of the plants. 3. Grab the holding strap. 4. Using the holding string, tie the plant and the holding rod in a figure-eight method.
Harvesting	Low	1. Grab a harvest basket. 2. Harvest the lettuce leaves freely from the vegetable garden box where different types of lettuce are planted.
	High	1. Grab the harvest basket. 2. Select the lettuce variety to harvest from among the three types of lettuce planted in the garden box. 3. Harvest lettuce leaves that meet the specifications for the selected lettuce variety.
Sowing	Low	1. Make holes with your fingers in the seed tray filled with potting soil. 2. Pick up one kidney bean. 3. Put the seed in the hole and cover it with soil.
	High	1. Pick up the lettuce seeds by hand. 2. Unwrap the lettuce seeds in a flask of water. 3. Use a dropper to siphon two to thee lettuce seeds with the water. 4. Squirt water and seeds into the center of the first hole of the seed tray filled with culture soil.
Performing cuttage (cutting)	Low	1. Separate one fleshy leaf. 2. Insert the cuttings into the cutting tray containing the culture soil at appropriate intervals.
	High	1. Cut tree branches at intervals of two to three nodes. 2. Leave only one-third of the top leaf and cut it. 3. Remove all the lower leaves. 4. Apply root growth promoter to the tip of the lower part. 5. Insert them, at 5- to 7-cm intervals, into the cutting tray containing the culture soil.
Planting potted plants	Low	1. Place a standardized flower pot net on the bottom of the pot. 2. Fill the bottom one-third of the pot with culture soil. 3. Transfer the entire jiffy pot with plants into the pot. 4. Fill the empty space with potting soil.
	High	1. Cut the flower pot net to the size suitable for the bottom of the pot. 2. Lay decomposed granite soil to a height of 2 to 3 cm. 3. Fill the bottom one-third of the pot with culture soil. 4. Isolate the plant from the pot. 5. Transfer the separated plants to pots. 6. Fill the empty space with potting soil. 7. Spread decomposed granite soil thinly on the surface.
Cutting and washing	Low	1. Wash the lettuce leaves in running water.
	High	1. Remove the wilted leaves from the entire bunch of lettuce. 2. Use a knife to remove the stem (root) of the lettuce. 3. Separate the lettuce leaves. 4. Wash each leaf under running water. 5. Separate the lettuce leaves by size.
Arranging flowers	Low	1. Insert the trimmed flowers freely into the floral foam.
	High	1. Trim the flowers using garden shears. 2. Use trimmed flowers as they are or weave them with wire. 3. Decorate the circle wreath freely.

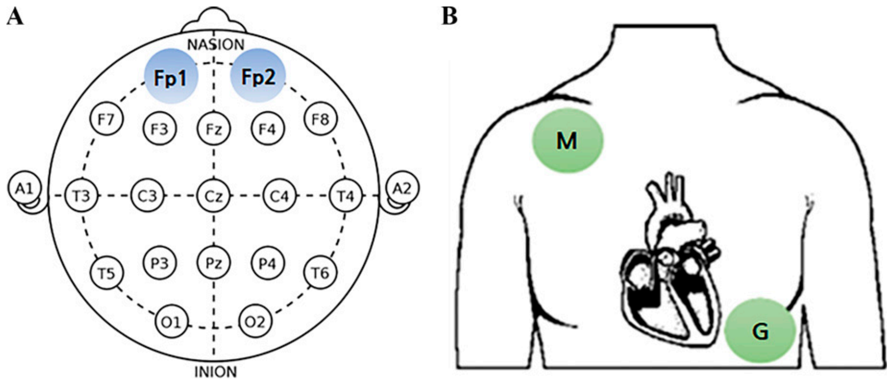

Fig. 3. International electrode arrangement (Stevens et al. 2016). (**A**) The channels in bold type, shaded in blue (Fp1 and Fp2) were measured in this study. (**B**) Electrode placement in electrocardiography. G = ground electrode; M = measuring electrode.

cognitive difficulty. In planting potted plants, RFA and RLB indices increased in the bilateral PFC when performing tasks at a high level of cognitive difficulty ($P < 0.05$), and RG indices decreased in the left PFC ($P < 0.05$). With regard to arranging flowers, when performing tasks at a high level of cognitive difficulty, the RB index increased in the bilateral PFC ($P < 0.01$) and the RT index decreased in the left PFC ($P < 0.01$). In terms of raking, there were no significant differences according to level of cognitive difficulty ($P > 0.05$).

Comparison of activities. Significant differences were found between the activities in the RT power spectra of both prefrontal lobes ($P > 0.001$) (Table 4). In the bilateral PFC, when cuttage was performed at a high cognitive difficulty, the RT was the lowest compared with the other activities. When fertilizing, sowing, performing cuttage, and arranging flowers were performed at a low level of cognitive difficulty, the RT was higher than for other activities.

Electrocardiography

The ECG results showed a tendency to relax and stabilize when performing activities at a low level of cognitive difficulty compared with high cognitive difficulty. The heart rate during sowing decreased significantly for low-cognitive difficulty activities ($P < 0.001$) (Table 5). When harvesting and planting potted plants at a high level of cognitive difficulty, the low frequency increased and the high frequency decreased ($P < 0.05$). The standard deviation of NN intervals (SDNN) increased significantly when planting transplants, and cutting and washing at a high level of cognitive difficulty ($P < 0.05$). No significant differences were found in raking, fertilizing, tying plants to stakes, performing cuttage, and arranging flowers ($P > 0.05$).

Semantic differential method

The SDM results for activity difficulty are shown in Table 6. In terms of comfort, there was a significant increase in the activities of tying plants to stakes, harvesting, performing cuttage, cutting and washing, and arranging flowers at a low level of cognitive difficulty ($P < 0.05$). Regarding the relaxed aspect, it increased significantly when raking, planting transplants, harvesting, performing cuttage, planting potted plants, and cutting and washing were performed at a low level of cognitive difficulty ($P < 0.05$). In terms of the natural aspect, there was a significant increase when fertilizing, harvesting, performing cuttage, planting potted plants, cutting and washing, and arranging flowers were performed at a low level of cognitive difficulty ($P < 0.05$). No significant differences were found for sowing ($P > 0.05$). In nine horticultural activities, except sowing, when the cognitive demand for the activity was low, there was a more positive effect on the emotional aspect than when the cognitive demand for the activity is high.

Discussion

This study investigated the psychophysiological responses of 32 adults according to the level of cognitive demand required for various horticultural activities. EEG and ECG measurements of the PFC were acquired to determine changes according to the level of cognitive demand required for gardening activities, and emotional states were compared using the SDM. EEG results were compared for the nine activities, excluding raking. When tasks were performed at a high level of cognitive difficulty, compared with the low level, RT decreased, and RB, RG, RFA, and RLB increased, indicating activation of the PFC ($P < 0.05$) (Table 3). The EEG results showed that RT was lowest when performing cuttage at a high level of cognitive difficulty, and it was high when fertilizing, sowing, performing cuttage, and arranging flowers were performed at a low level ($P < 0.001$) (Table 4). The ECG results showed that the sympathetic nervous system was activated and the parasympathetic nervous system was suppressed when performing activities with high cognitive demands ($P < 0.05$) (Table 5). The SDM showed that when performing nine activities at the low level of cognitive difficulty (the exception was sowing), a more positive mood state was felt than when performing these tasks at a high level of cognitive difficulty ($P < 0.05$) (Table 6).

The frontal lobe is located in the anterior part of the cerebral hemisphere; it controls higher mental processes and plays a role in coordinating information coming from other associations of the body and controlling behavior (Pope et al. 2019). It also plays an important role in various cognitive processes, such as attention, memory, and language (Chayer and Freedman 2001). In particular, the front part of the frontal lobe is called the PFC, and it plays an important role in cognitive functions, such as binding information to create a balanced system and executing planned contents (Siddiqui et al. 2008).

Brain waves occur naturally in both the active and resting states, and human thoughts, emotions, and behaviors reflect neural activity inside the brain (Sowndhararajan et al. 2015). Electroencephalography can relate different frequencies to brain activity by measuring the electrophysiological signals that occur in the brain (García-Monge et al. 2020). They are generally divided into delta (0–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–50 Hz) bands, according to the frequency bands that represent specific functional roles (Staufenbiel et al. 2014). In our study, the five indices RT, RB, RG, RFA, and RLB were used as parameters.

The RFA index increased when planting transplants, performing cuttage, potting plants, and cutting and washing at a high level of cognitive difficulty ($P < 0.05$) (Table 3). The RFA index is activated primarily when emotional anxiety is stabilized (Park 2005). Increased fast alpha waves can awaken the brain to a comfortable resting state and improve cognitive abilities (Kim et al. 2022). When sowing, performing cuttage, and arranging flowers were done at a high level of cognitive difficulty, the RT index decreased and the RB index increased in the PFC. In addition, the RLB index increased when planting transplants, harvesting, potting plants, and cutting and washing activities were performed at high cognitive difficulty. The RT band plays an important role in cognitive processing, memory, and learning mechanisms (García-Monge et al. 2020). In

Table 2. Study participant demographics.

Variable	Male (n = 16)	Female (n = 16)	Total (N = 32)
Age (years, mean ± *SD*)[i]	24.9 ± 3.3	21.6 ± 1.5	23.2 ± 3.0
Height (cm, mean ± *SD*)[ii]	171.5 ± 6.3	161.4 ± 5.9	166.4 ± 7.9
Body weight (kg, mean ± *SD*)[iii]	66.0 ± 7.6	57.6 ± 10.6	61.8 ± 10.0
Body mass index ($kg \cdot m^{-2}$, mean ± *SD*)[iv]	22.5 ± 3.3	22.2 ± 3.7	22.4 ± 3.4

[i] *SD* = standard deviation.

[ii] Participants removed shoes before their height was measured using an anthropometer (Ok7979; Samhwa, Seoul, South Korea).

[iii] Body weight was measured using a body fat analyzer (ioi 353; Jawon Medical, South Korea).

[iv] Body mass index was calculated using the formula [Weight (kg)]/[Height (m^2)].

Table 3. Encephalographic results according to activity (N = 32).

Activity	Cognitive demand	RT[i]		RB[ii]		RG[iii]		RFA[iv]		RLB[v]	
		Fp1[vi]	Fp2[vii]	Fp1	Fp2	Fp1	Fp2	Fp1	Fp2	Fp1	Fp2
Raking	Low level	0.29 ± 0.07[viii]	0.29 ± 0.07	0.30 ± 0.04	0.30 ± 0.04	0.24 ± 0.06	0.24 ± 0.06	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
	High level	0.30 ± 0.07	0.29 ± 0.08	0.29 ± 0.03	0.29 ± 0.04	0.24 ± 0.07	0.24 ± 0.07	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
	Significance[ix]	0.408 NS	0.936 NS	0.423 NS	0.778 NS	0.575 NS	0.902 NS	0.809 NS	0.567 NS	0.250 NS	0.473 NS
Planting transplants	Low level	0.31 ± 0.09	0.31 ± 0.08	0.29 ± 0.04	0.29 ± 0.04	0.23 ± 0.07	0.23 ± 0.06	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.02	0.08 ± 0.01
	High level	0.32 ± 0.07	0.31 ± 0.07	0.29 ± 0.04	0.29 ± 0.04	0.22 ± 0.05	0.22 ± 0.05	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.02	0.08 ± 0.01
	Significance	0.790 NS	0.715 NS	0.567 NS	0.701 NS	0.263 NS	0.160 NS	0.048*	0.043*	0.003**	0.009**
Fertilizing	Low level	0.34 ± 0.07	0.33 ± 0.07	0.28 ± 0.04	0.28 ± 0.04	0.021 ± 0.05	0.22 ± 0.05	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.07 ± 0.01
	High level	0.32 ± 0.06	0.31 ± 0.07	0.28 ± 0.03	0.29 ± 0.04	0.24 ± 0.05	0.24 ± 0.07	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	Significance	0.103 NS	0.225 NS	0.883 NS	0.413 NS	0.006**	0.039*	0.007**	0.025*	0.006**	0.110 NS
Tying plants to stakes	Low level	0.33 ± 0.06	0.31 ± 0.07	0.28 ± 0.04	0.29 ± 0.04	0.21 ± 0.05	0.22 ± 0.06	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
	High level	0.31 ± 0.07	0.31 ± 0.07	0.29 ± 0.04	0.29 ± 0.04	0.23 ± 0.05	0.23 ± 0.06	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	Significance	0.087 NS	0.752 NS	0.867 NS	0.206 NS	0.006**	0.062 NS	0.225 NS	0.552 NS	0.020*	0.018*
Harvesting	Low level	0.30 ± 0.09	0.30 ± 0.08	0.29 ± 0.05	0.29 ± 0.04	0.24 ± 0.08	0.24 ± 0.06	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01	0.08 ± 0.01
	High level	0.31 ± 0.07	0.30 ± 0.08	0.29 ± 0.04	0.29 ± 0.04	0.22 ± 0.06	0.23 ± 0.07	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.07 ± 0.01
	Significance	0.405 NS	0.943 NS	0.441 NS	0.836 NS	0.270 NS	0.616 NS	0.307 NS	0.286 NS	0.043*	0.184 NS
Sowing	Low level	0.34 ± 0.06	0.33 ± 0.06	0.27 ± 0.03	0.28 ± 0.03	0.23 ± 0.04	0.24 ± 0.05	0.05 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
	High level	0.31 ± 0.06	0.30 ± 0.06	0.28 ± 0.03	0.29 ± 0.03	0.26 ± 0.05	0.27 ± 0.05	0.05 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
	Significance	0.001**	0.000***	0.052 NS	0.003**	0.002**	0.000***	0.459 NS	0.685 NS	0.406 NS	0.790 NS
Performing cuttage (cutting)	Low level	0.34 ± 0.08	0.33 ± 0.07	0.27 ± 0.04	0.28 ± 0.03	0.24 ± 0.05	0.24 ± 0.06	0.05 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
	High level	0.22 ± 0.03	0.22 ± 0.04	0.36 ± 0.03	0.37 ± 0.03	0.26 ± 0.03	0.26 ± 0.03	0.06 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
	Significance	0.000***	0.000***	0.000***	0.000***	0.007**	0.037*	0.000***	0.000***	0.000***	0.000***
Planting potted plants	Low level	0.33 ± 0.07	0.32 ± 0.07	0.27 ± 0.04	0.27 ± 0.03	0.25 ± 0.05	0.24 ± 0.05	0.05 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
	High level	0.33 ± 0.06	0.32 ± 0.05	0.27 ± 0.03	0.28 ± 0.03	0.23 ± 0.05	0.24 ± 0.05	0.0.5 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	Significance	0.298 NS	0.610 NS	0.703 NS	0.201 NS	0.033*	0.353 NS	0.001**	0.047*	0.002**	0.017*
Cutting and washing	Low level	0.32 ± 0.05	0.31 ± 0.06	0.28 ± 0.03	0.28 ± 0.03	0.24 ± 0.04	0.25 ± 0.04	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	High level	0.32 ± 0.05	0.31 ± 0.05	0.28 ± 0.03	0.28 ± 0.03	0.23 ± 0.04	0.24 ± 0.04	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	Significance	0.759 NS	0.929 NS	0.965 NS	0.813 NS	0.189 NS	0.217 NS	0.013*	0.006**	0.016*	0.018*
Arranging flowers	Low level	0.35 ± 0.06	0.33 ± 0.05	0.26 ± 0.03	0.27 ± 0.03	0.23 ± 0.05	0.24 ± 0.05	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	High level	0.33 ± 0.05	0.32 ± 0.05	0.27 ± 0.03	0.28 ± 0.03	0.23 ± 0.05	0.23 ± 0.05	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
	Significance	0.045*	0.472 NS	0.000***	0.003**	0.464 NS	0.782 NS	0.889 NS	0.779 NS	0.498 NS	0.347 NS

[i] Relative theta power spectra (RT) was calculated as [Theta (4–8) power]/[Total frequency (4–50 Hz) power].
[ii] Relative beta power spectra (RB) was calculated as [Beta (13–30) power]/[Total frequency (4–50 Hz) power].
[iii] Relative gamma power spectra (RG) was calculated as [Gamma (30–50) power]/[Total frequency (4–50 Hz) power].
[iv] Relative fast-alpha power spectra (RFA) was calculated as [Fast-alpha (11–13) power]/[Total frequency (4–50 Hz) power].
[v] Relative low-beta power spectra (RLB) was calculated as [Low-beta (12–15 Hz) power]/[Total frequency (4–50 Hz) power].
[vi] Fp1 = left prefrontal lobe.
[vii] Fp2 = right prefrontal lobe.
[viii] Mean ± standard deviation.
[ix] NS, *, **, *** nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, by paired t tests.

Table 4. Results of the relative theta power spectra[i] by electroencephalography according to activity (N = 32).

Channel[ii]	Cognitive demand	Raking	Planting transplants	Fertilizing	Tying plants to stakes	Harvesting	Sowing	Performing cuttage (cutting)	Planting potted plants	Cutting and washing	Arranging flowers	P value[iii]
Fp1	Low level	0.29 ± 0.07 c[iv]	0.31 ± 0.09 a–c	0.34 ± 0.07 a	0.33 ± 0.06 a–c	0.30 ± 0.09 a–c	0.34 ± 0.06 a	0.34 ± 0.08 a	0.33 ± 0.07 a–c	0.32 ± 0.05 bc	0.35 ± 0.06 a	0.000***
	High level	0.30 ± 0.07 bc	0.32 ± 0.07 a–c	0.32 ± 0.06	0.31 ± 0.07 a–c	0.31 ± 0.07 a–c	0.31 ± 0.06 a–c	0.22 ± 0.03 d	0.33 ± 0.06 ab	0.32 ± 0.05 a–c	0.33 ± 0.05 ab	
Fp2	Low level	0.29 ± 0.07 c	0.31 ± 0.08 ab	0.33 ± 0.07 ab	0.31 ± 0.07 ab	0.30 ± 0.08 ab	0.33 ± 0.06 ab	0.33 ± 0.07 a	0.32 ± 0.07 ab	0.31 ± 0.06 ab	0.33 ± 0.05 ab	0.000***
	High level	0.29 ± 0.08 ab	0.31 ± 0.07 ab	0.31 ± 0.07 ab	0.31 ± 0.07 ab	0.30 ± 0.08 ab	0.30 ± 0.06 ab	0.22 ± 0.04 d	0.32 ± 0.05 ab	0.31 ± 0.05 ab	0.32 ± 0.05 ab	

[i] RT was calculated as follows: [Theta (4–8) power]/[Total frequency (4–50 Hz) power].
[ii] Fp1 = left prefrontal lobe; Fp2 = right prefrontal lobe.
[iii] NS, *, **, *** nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, by one-way analysis of variance. The statistical method used Duncan's post hoc analysis ($a > b > c > d$). The lowercase letters indicate the group to which the activities belong when performing analysis using Duncan.
[iv] Mean ± standard deviation.

Table 5. Results of heart rate variability according to activity (N = 32).

Activity	Cognitive demand	Heart rate	Low frequency[i]	High frequency[ii]	SDNN[iii]
Raking	Low level	124.24 ± 40.79[iv]	0.45 ± 0.09	0.55 ± 0.09	90.43 ± 88.53
	High level	121.79 ± 20.06	0.47 ± 0.08	0.53 ± 0.082	93.77 ± 60.57
	Significance[v]	0.745 NS	0.246 NS	0.246 NS	0.823 NS
Planting transplants	Low level	105.12 ± 28.06	0.49 ± 0.10	0.51 ± 0.10	75.08 ± 38.82
	High level	111.51 ± 20.67	0.48 ± 0.08	0.52 ± 0.08	87.97 ± 34.12
	Significance	0.197 NS	0.661 NS	0.661 NS	0.045*
Fertilizing	Low level	100.16 ± 13.04	0.52 ± 0.10	0.48 ± 0.10	70.88 ± 95.83
	High level	98.17 ± 15.56	0.50 ± 0.10	0.50 ± 0.10	79.36 ± 31.38
	Significance	0.324 NS	0.363 NS	0.363 NS	0.673 NS
Tying plants to stakes	Low level	99.67 ± 14.60	0.53 ± 0.10	0.47 ± 0.10	85.32 ± 37.14
	High level	97.20 ± 14.33	0.51 ± 0.11	0.49 ± 0.11	80.77 ± 36.58
	Significance	0.173 NS	0.084 NS	0.084 NS	0.332 NS
Harvesting	Low level	92.12 ± 10.18	0.53 ± 0.11	0.47 ± 0.11	57.17 ± 33.98
	High level	90.49 ± 19.87	0.60 ± 0.11	0.40 ± 0.11	66.75 ± 34.23
	Significance	0.655 NS	0.000***	0.000***	0.249 NS
Sowing	Low level	86.91 ± 10.39	0.51 ± 0.09	0.49 ± 0.09	35.06 ± 13.87
	High level	84.04 ± 10.40	0.49 ± 0.09	0.51 ± 0.09	36.80 ± 13.43
	Significance	0.000***	0.252 NS	0.252 NS	0.156 NS
Performing cuttage (cutting)	Low level	84.19 ± 9.42	0.49 ± 0.08	0.51 ± 0.08	41.05 ± 16.41
	High level	85.61 ± 12.78	0.49 ± 0.08	0.51 ± 0.08	45.77 ± 22.07
	Significance	0.227 NS	0.855 NS	0.855 NS	0.108 NS
Planting potted plants	Low level	87.84 ± 12.23	0.53 ± 0.10	0.47 ± 0.10	46.89 ± 24.78
	High level	88.90 ± 16.82	0.50 ± 0.08	0.50 ± 0.08	50.56 ± 30.82
	Significance	0.333 NS	0.032*	0.032*	0.438 NS
Cutting and washing	Low level	95.42 ± 11.23	0.53 ± 0.12	0.47 ± 0.012	43.19 ± 23.10
	High level	96.08 ± 11.96	0.50 ± 0.11	0.50 ± 0.11	51.86 ± 29.75
	Significance	0.570 NS	0.056 NS	0.056 NS	0.039*
Arranging flowers	Low level	88.06 ± 21.17	0.50 ± 0.82	0.50 ± 0.82	52.89 ± 32.18
	High level	86.81 ± 14.38	0.51 ± 0.82	0.49 ± 0.82	45.25 ± 26.61
	Significance	0.523 NS	0.776 NS	0.776 NS	0.050 NS

[i] Calculated as [Low-frequency band (0.04–0.15 Hz)]/[Total-frequency band (0.04–0.4 Hz)].
[ii] Calculated as [Low-frequency band (0.15–0.4 Hz)]/[Total-frequency band (0.04–0.4 Hz)].
[iii] SDNN = standard deviation of NN intervals between the R-peaks of the heartbeat.
[iv] Mean ± standard deviation.
[v] NS, *, **, *** nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, by paired t tests.

particular, theta and upper alpha waves play important roles in building working memory and long-term memory (Karakaş 2020). A reduction in theta waves indicated that cognitive function was activated. In addition, the RB band increases when attention is focused, such as when paying attention, solving problems, and making decisions (Neuper and Pfurtscheller 2001). Beta waves are classified into low, mid, and high beta waves. Their activation is related to academic performance, and they can help improve cognitive function (Sowndhararajan et al. 2015). The RG index increased when fertilizing, tying plants to stakes, sowing, and performing cuttage were performed at high cognitive difficulty. The RG band is related to perceptual coupling, such as attention, arousal, and learning (Fries 2015; Wang 2010), and occurs particularly in conjunction with various cognitive processes (Herrmann et al. 2004). This indicates that horticultural activities with high cognitive difficulty activate cognitive function by awakening the PFC.

When performing cuttage was performed at a high level of cognitive difficulty, the RT index appeared to be the lowest, indicating that working memory function was activated the most compared with other activities ($P < 0.001$) (Table 4). In addition, when the fertilizing, sowing, performing cuttage, and arranging flowers were performed at low cognitive difficulty, the RT index was high, indicating they required the least cognitive load. This indicates there are differences in the levels of cognitive difficulty associated with horticultural activities.

HRV reflects the interaction between the sympathetic nervous system and the parasympathetic nervous system of the autonomic nervous system (Kabisch et al. 2021). Changes in heart rate, the ratio of low frequency to high frequency, and SDNN were evaluated over time according to the time domain analysis method (Park and Jeong 2014). The sympathetic nervous system dominates under conditions of increased activity and stress, and HRV increases when stimulated (Gidlow et al. 2016; Pham et al. 2021; Shaffer and Ginsberg 2017). The parasympathetic nervous system predominates in quiet and relaxed states, and is associated with decreased HRV (Pham et al. 2021). In our study, when sowing at a low level of cognitive difficulty, the heart rate was lowered and stabilized ($P < 0.05$) (Table 5). The ratio of low frequency to high frequency increased when harvesting and planting potted plants were performed at a high level of cognitive difficulty ($P < 0.05$). In addition, the SDNN, which represents the standard deviation of the NN intervals between R-peaks of the heartbeat, increased when planting transplants and cutting and washing were performed at a high level of cognitive difficulty ($P < 0.05$). This means that when performing an activity at high cognitive difficulty, a greater stress level is experienced than when performing an activity at a low level of cognitive difficulty.

Table 6. Results of the semantic differential method according to activity (N = 32).

Activity	Cognitive demand	Comfortable/ uncomfortable	Relaxed/awake	Natural/artificial
Raking	Low level	2.72 ± 1.859[i]	2.31 ± 2.13	2.81 ± 1.84
	High level	2.38 ± 1.77	1.53 ± 2.68	2.94 ± 2.14
	Significance[ii]	0.155 NS	0.029*	0.658 NS
Planting transplants	Low level	3.25 ± 1.80	3.41 ± 1.50	2.81 ± 1.89
	High level	2.81 ± 1.69	2.56 ± 2.21	2.28 ± 2.05
	Significance	0.090 NS	0.020*	0.91 NS
Fertilizing	Low level	2.31 ± 2.24	2.31 ± 2.29	2.34 ± 2.25
	High level	1.94 ± 2.21	1.72 ± 2.37	1.78 ± 2.24
	Significance	0.142 NS	0.079 NS	0.045*
Tying plants to stakes	Low level	1.56 ± 2.21	1.50 ± 2.24	1.81 ± 2.62
	High level	0.91 ± 2.18	1.03 ± 1.87	1.41 ± 2.39
	Significance	0.013*	0.096 NS	0.266 NS
Harvesting	Low level	2.72 ± 2.07	2.50 ± 2.09	2.78 ± 2.21
	High level	2.19 ± 2.28	1.97 ± 2.10	2.16 ± 2.40
	Significance	0.042*	0.030*	0.006**
Sowing	Low level	3.47 ± 1.80	3.47 ± 1.63	2.56 ± 2.24
	High level	3.06 ± 2.03	2.84 ± 1.97	2.19 ± 2.46
	Significance	0.191 NS	0.050 NS	0.259 NS
Cuttage (Cutting)	Low level	3.28 ± 1.67	3.09 ± 1.75	2.91 ± 1.99
	High level	1.84 ± 1.99	1.34 ± 2.35	1.22 ± 2.25
	Significance	0.000***	0.000***	0.000***
Planting potted plants	Low level	3.28 ± 1.80	3.28 ± 2.04	2.88 ± 2.18
	High level	2.28 ± 2.23	1.78 ± 2.43	1.91 ± 2.36
	Significance	0.002**	0.000***	0.017*
Cutting and Washing	Low level	2.78 ± 2.38	2.63 ± 2.18	2.59 ± 1.83
	High level	1.97 ± 2.47	1.81 ± 2.56	1.81 ± 2.42
	Significance	0.005**	0.027*	0.041*
Flower arrangement	Low level	3.28 ± 2.37	3.19 ± 2.32	2.38 ± 2.64
	High level	2.81 ± 2.26	2.91 ± 2.15	1.78 ± 2.42
	Significance	0.017*	0.184 NS	0.030*

[i] Mean ± standard deviation.

[ii] NS, *, **, *** nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, by paired t tests.

As a result of measuring the emotional states of people performing gardening activities according to cognitive difficulty using the SDM, significant differences were found in nine horticultural activities ($P < 0.05$; sowing was the exception) (Table 6). There is a significant difference in psychological emotions when the cognitive demand for the activity is high and when the cognitive demand for the activity is low in nine horticultural activities (sowing excluded). According to a previous study (Kim et al. 2022), there was no significant difference in cognitive demand when performing a soil-mixing activity, and this affected the activity of the frontal cortex without affecting the subjective psychological state. However, the results of our study show that there are activities that are affected by the emotional state according to level of cognitive difficulty and type of gardening activity.

In previous studies, the effects of horticultural activities on cognitive function have been identified, and the effects of single horticultural activities have been measured according to the level of cognitive demand used to complete them. In our study, various horticultural activities were divided into two levels of cognitive demand, and the effects on participants' PFC activity and emotional state were investigated. We found that performing tasks at a high level of cognitive difficulty was more effective in activating cognitive functions and increasing attention than activities completed at a low level of cognitive difficulty. In addition, activities done at a low level of cognitive difficulty have a more positive effect on emotional stability than those performed at a high level. However, because the participants in this study were limited to adults in their 20s, it is difficult to generalize the results to all age groups. Thus, additional research is needed to expand this study and investigate the effects of various horticultural activities and levels of cognitive demand on participants' cognitive function according to age group. Moreover, no significant difference in EEG results was observed with the raking activity. This suggests that the level of difficulty used to perform this activity was not extreme enough to effect a difference.

We measured the effects of various horticultural activities, performed at two levels of cognitive demand, on the psychophysiological responses of adults. With most of the 10 horticultural activities, the higher the level of cognitive demand required to perform the task, the greater the activity in the PFC, which activates cognitive function and attention. Depending on the level of cognitive demand, there is a difference in the amount of cognitive load required from participants. These results show the need for an intervention with an appropriate cognitive level of difficulty for the subject according to the purpose of horticultural activity (relaxation, training, etc.). The results of this study are believed to influence the control of cognitive function stimulation and fatigue through the intervention of an appropriate level of cognitive demand. In addition, this study provides basic data for the development of professional horticultural therapy treatment programs based on scientific evidence tailored to the subject.

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