HORTSCIENCE 59(9):1386–1390. 2024. https://doi.org/10.21273/HORTSCI17887-24

Analysis of Prefrontal Cortex Responses According to Oxyhemoglobin Concentration Changes in Participants Undertaking Horticultural Activities

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Keywords. cerebral blood flow, functional near-infrared spectroscopy, gardening, prefrontal cortex stabilization, sensorial stimulation

***Abstract.* This study aimed to investigate the psychophysiological effects of horticultural activities on the prefrontal cortex (PFC) to understand how horticultural activities can influence mental health and cognitive function. This study involved 39 adults with an average age of 54.6 years (±12.5 years) and was conducted in a laboratory setting at Konkuk University. The impact of five different types of horticultural activities—sowing, transplanting, planting, harvesting, and packaging—on PFC oxyhemoglobin (oxy-HB) concentrations was assessed. Functional near-infrared spectroscopy (fNIRS) was used to measure oxy-HB levels in the PFC while participants engaged in each activity for 90 seconds. The results indicated that the overall PFC oxy-HB concentration was at its lowest during planting and at its highest during sowing ($P < 0.001$). In the right PFC, oxy-HB was also at its lowest during planting and at its highest during sowing ($P < 0.01$). In the left PFC, the lowest oxy-HB concentrations were observed during both planting and harvesting, whereas the highest oxy-HB concentrations were observed during transplanting and sowing ($P < 0.001$). Additionally, sex-based differences were noted, with females showing significantly lower oxy-HB concentrations during sowing ($P < 0.05$) and transplanting ($P < 0.01$) than those of males. These findings suggested that psychophysiological responses, as indicated by oxy-HB concentrations, vary depending on the type of horticultural activity and by sex.**

With the emergence of megacities comprising more than 10 million residents (Kennedy et al. 2014), people in modern society have experienced reduced contact with nature. This can be attributed to the presence of various artificial elements (Ohly et al. 2016). As a result, individuals are exposed to various environmental stressors. According to the attention restoration theory, modern urban living increases the demand for cognitive resources, which leads to attention fatigue (Kaplan and Berman 2010). Highly urbanized and artificial environments exacerbate human stress levels (Dye 2008). Moreover, growing up in an urban environment affects the ventromedial prefrontal cortex (PFC), which is the brain area with a key role in regulating amygdala activity. Urban living can increase amygdala activity, thus leading to negative health effects (Lederbogen et al. 2011) and stress (Haddad et al. 2015). Because of these negative effects, there is a growing interest in human health and well-being connected with nature, and several studies have shown that spending time and interacting with nature can improve well-being (Franco et al. 2017; Hansen et al. 2017a). Nature therapy, which includes exposure to natural stimuli such as forests, urban green spaces, plants, and natural wooden materials, aims to promote health by preventing the negative effects of urban living (Hansen et al. 2017b; Song et al. 2016).

The physiological and psychological changes that occur during natural visual stimulation in adults have been assessed. For example, studies that measured visual stimulation reported that looking at plants increased the participants' alpha waves and blood pressure and decreased their heart rate (Jeong and Park 2021). Similar visual studies have shown that when participants look at plants instead of an empty wall, the oxyhemoglobin (oxy-HB) concentration in the PFC decreases, indicating stabilization of the PFC (Park et al. 2016). Self-report surveys also evaluated the idea that plants provide comfort and have a positive impact on health (Igarashi et al. 2015; Oh et al. 2019a). Moreover, when participants viewed natural indoor environments, they experienced reduced anxiety and tension, increased alpha and beta waves, and decreased blood pressure (Chang and Chen 2005; Hartig et al. 2003).

Gardening activities entail a series of operating tasks and provide opportunities for the development of various vocational interests. They can enhance manual skills, improve muscle activity in the upper and lower limbs, and contribute to the development of occupational skills (Lee et al. 2012; Park et al. 2009a). A comparative study of individuals with disabilities who worked in a greenhouse and those who worked in sheltered workshop training facilities found that participants who worked in the greenhouse experienced reduced stress, as evidenced by decreased systolic blood pressure and diastolic blood pressure. Furthermore, occupational training involving gardening leads to improved job skills (Lee et al. 2018a).

Another study reported that participants who engaged in agriculture through gardening activities exhibited better physical health and improved horticultural skills (Oh et al. 2019b). The psychological effects included enhanced self-esteem and confidence, improved quality of life, emotional stability, improved interpersonal relationships, and increased trust in others (Hine et al. 2008). However, most studies of the health effects of agriculture have been based on a holistic approach and involved comparisons before and after agricultural activities or experimental and control interventions. Studies that have focused on the psychophysiological responses to horticultural activities are scarce (National Institute of Horticultural and Herbal Science 2018).

Therefore, in this study, we analyzed the differences in oxy-HB concentrations in the PFC using functional near-infrared spectroscopy (fNIRS) during horticultural activities. By using advanced neuroimaging techniques, this research provides a detailed understanding of the psychophysiological responses elicited by gardening, thereby addressing a significant gap in the literature regarding nature therapy and its benefits.

Materials and Methods

Participants. This study included 39 adults 20 years of age or older; there were 15 male and 24 female participants (38.4% men and 61.5% women). The sample size was determined based on the assumption of a normal distribution in the population, which has been commonly observed in previous psychophysiological studies of gardening activities; the typical recommended sample size is more than 30 (Kim et al. 2020). This number was chosen to balance the need for sufficient statistical power with the practical constraints of conducting detailed neurophysiological measurements using fNIRS. To recruit participants, leaflets and posters that provided information about

Received for publication 12 Apr 2024. Accepted for publication 1 Jul 2024.
Published online 27 Aug 2024.
N.-Y.Y. and S.-H.K. contributed equally to this work.
This work was performed with the support of "Cooperative Research Program for Agriculture Science and Technology Development (project no.: RS-2021-RD009660)" Rural Development Administration, Republic of Korea.
The datasets generated for this study are available on request to the corresponding author.
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the study were made available to the general public at welfare centers, schools, and libraries near Gwangjin-gu in Seoul. The selection criteria followed those of the study by Tarkka and Hallett (1990), which focused on right-hand-dominant individuals and excluded those with specific medical conditions (Choi et al. 2016). Additionally, the participants were asked to fast for 3 h before the experiment to minimize the influence of caffeine (Heckman et al. 2010). Adult volunteer participants were briefed about the study's purpose, procedures, and expected outcomes, and they signed informed consent forms for participation. This study was approved by the Institutional Review Board of Konkuk University (7001355-202209-HR-586).

Experimental setting. The experiment was conducted in a laboratory located on the campus of Konkuk University. According to the International Facility Management Association standards for workspace areas, the internal space of the laboratory was set to 2.0 m × 2.0 m. The indoor environment was regulated according to the recommendations of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, with a temperature of 23.0 to 26.0 °C, relative humidity of 30% ± 10%, lighting of 700 lx, and noise levels less than 40 dB. To block external visual elements and create a sealed experimental environment, ivory blackout curtains were installed. Additionally, for therapeutic horticultural activities, a white table (width, 180 cm; length, 90 cm; height, 70 cm) and adjustable ergonomic chairs were provided.

Experimental procedure. Participants were asked to rest without moving and remain silent for 5 min to establish a stable baseline state. Subsequently, they engaged in five horticultural activities (sowing, transplanting, planting out, harvesting, and packaging) in a seated position for 90 s each (experimental protocol in Fig. 1). The sowing activity involved transferring lettuce (*Lactuca sativa*) seeds to premade holes in a seeding tray using sterilized tweezers. Participants were instructed to handle the seeds gently and ensure that they were evenly spaced in the tray. During the transplanting activity, participants moved small lettuce seedlings (∼5 cm in height) from a separate tray onto a designated seedling tray. They were encouraged to place each seedling carefully into the soil to promote optimal growth conditions. The planting out activity required participants to transfer larger lettuce seedlings (height, ≥10 cm) from the seedling tray to a larger container with nutrient-rich soil. This step simulated the process of preparing seedlings for transplantation into a garden or larger growing area. For the harvesting activity, participants harvested mature lettuce plants (height, ≥10 cm) from the seedling tray. They were instructed to cut the lettuce cleanly at the base of the plant to preserve its quality and appearance by mimicking practices used in commercial or home gardening. Finally, the packaging activity involved sorting and packaging the harvested lettuce. Participants were provided with containers and instructed to organize the lettuce neatly after considering the size and quality as if preparing it for sale or personal consumption (Table 1).

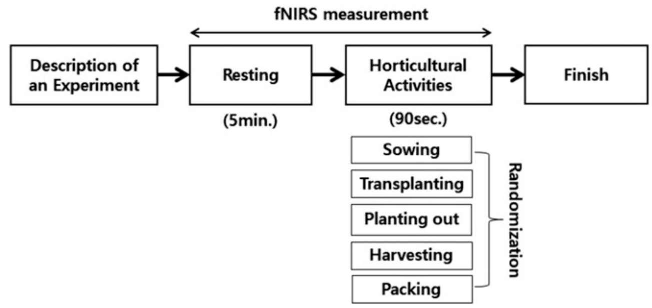

Fig. 1. Experimental protocol.

Measurements. Basic data regarding oxy-HB concentrations in the PFC were collected from participants using fNIRS. Variations in oxy-HB concentrations derived from measuring hemoglobin values in the PFC were assessed to elucidate differences in performance during activities. The fNIRS equipment used in this study was NIRSIT Lite (OBELAB Inc., Seoul, Republic of Korea), which encompasses channels within the Brodmann area, including the anterior PFC (channels 2–14), dorsolateral PFC (channel 1), and orbital part of the inferior frontal gyrus (channel 15). The oxy-HB concentrations of participants were measured for 90 s in the entire PFC area and in the left and right regions of the PFC during the five horticultural activities; additionally, fNIRS, which is a noninvasive technique that uses near-infrared light to measure changes in cerebral blood flow, was performed (Lee et al. 2021). During the procedure, near-infrared light in the range of 700 to 1000 nm was sent to the scalp in the frontal cortex, and oxy-HB and deoxy-HB levels were measured to determine the blood oxygen concentration (Dmochowski et al. 2020). Compared with real-time brain imaging devices, such as functional magnetic resonance imaging or electroencephalography, fNIRS is more straightforward, less burdensome, and conveys minimal constraints related to movement, environment, or space. Moreover, its relatively high measurement speed makes it advantageous for real-time monitoring of brain activation (Ferrari and Quaresima 2012).

Data analysis. The fNIRS data used to understand brain activation characteristics during the five horticultural activities were analyzed as follows. The raw data were subjected to a low-pass filter with a discrete cosine transform applied at 0.1 and a high-pass filter with a discrete cosine transform at 0.0005. Channels with a signal-to-noise ratio less than 30 dB for 10 to 15 s were excluded from the analysis. Subsequently, the oxy-HB concentration was calculated using the modified Beer–Lambert law calculation process. Because of the larger change in oxy-HB levels compared with that in deoxy-HB levels during cerebral blood flow measurement, the oxy-HB variation was used for the analysis in this study (Jang and Yoon 2021). The baseline for this analysis was an average of the oxy-HB values recorded over a duration of 90 s before the start of the activity. To visualize hemoglobin, activation mapping was used to extract the average image over the 90-s duration of each task. A one-way analysis of variance and Duncan's post hoc tests were performed to examine the differences and rankings among the five activities. Independent *t* tests were performed to investigate oxy-HB concentration differences between sexes. The statistical significance level was set at 0.05 for all analyses of the differences among the five activities. Statistical software (IBM SPSS Statistics version 26.0; IBM Corp., Armonk, NY, USA) was used for the analyses.

Table 1. Detailed procedures and materials of the horticultural activities.

Agricultural activities		Procedure
Sowing lettuce seeds	1.	Soak the germination sponge in water
	2.	Transfer the coated lettuce seeds on the germination sponge (58 × 28) using intervals of 2 cm and a tweezer
	3.	Repeat procedures 1 and 2
Transplanting (small lettuce)	1.	Gather the lettuce from the germination sponge
Planting out (larger lettuce)	2.	Transplant the lettuce to another tray
	3.	Repeat procedure 1 and 2
Harvesting	1.	Select and gather the lettuce from the tray and place it on cutting board
	2.	Remove the base with a knife and place lettuce in baskets
	3.	Repeat procedure 1 and 2
Packaging	1.	Classify the lettuce for lettuce wraps and lettuce salads
	2.	After classifying lettuce, place it in a plastic-covered box (left box for lettuce salads; right box for lettuce wraps)
	3.	Repeat procedure 1 and 2

Results

Demographic characteristics. This study enrolled 39 adults 20 to 65 years of age (38.4% male participants; 61.5% female participants). Participants had a mean age of 50.7 years (±14.7 years), average height of 167.4 cm (±7.5 cm), and mean weight of 68.6 kg (±14.1 kg). The average body mass index was 24.7 kg/m^2 (±3.5 kg/m^2), which was within the normal range as defined by the Centers for Disease Control and Prevention (Table 2).

Table 2. General characteristics of participants.

Variance	Male participants (n = 15)	Female participants (n = 24)	Total (N = 39)
	Mean ± *SD*		
Age	50.7 ± 14.7	56.9 ± 10.8	54.6 ± 12.5
Height (cm)[i]	167.4 ± 7.5	152.7 ± 7.4	157.8 ± 10.3
Weight (kg)[ii]	68.6 ± 14.1	55.3 ± 7.6	60.1 ± 12.1
BMI (kg/m^2)[ii]	24.7 ± 3.5	23.8 ± 3.2	24.1 ± 3.3

[i] Height was measured using an anthropometer (OK7979; Samhwa, Seoul, South Korea) without shoes.
[ii] Body weight and body mass index were measured using a body fat analyzer (ioi 353; Jawon Medical, Seoul, South Korea).
BMI = body mass index.

Oxy-HB analysis by activity type. Significant variations in oxy-HB concentrations were observed across the PFC during the five horticultural activities ($P < 0.001$). Notably, planting out resulted in the lowest oxy-HB concentration, whereas sowing resulted in the highest. In the right PFC, planting out consistently resulted in the lowest oxy-HB concentration, whereas sowing resulted in the highest ($P < 0.01$). Within the left PFC, oxy-HB levels were the lowest during planting out and harvesting, and they were the highest during transplanting and sowing ($P < 0.001$) (Table 3).

Comparison of oxy-HB concentrations between the left and right PFC. A comparison of oxy-HB concentrations in the left and right PFC showed no significant differences across the five activities (sowing, transplanting, planting out, harvesting, and packaging) ($P > 0.05$) (Table 4).

Sex differences in oxy-HB concentrations by activity. Compared with male participants, female participants exhibited significantly lower oxy-HB concentrations during sowing ($P < 0.05$) and transplantation ($P < 0.01$). However, no significant differences were observed between the sexes during the remaining activities (planting out, harvesting, and packaging) ($P > 0.05$) (Table 5).

Discussion

This study measured changes in the PFC to evaluate the effects of five horticultural activities (sowing, transplanting, planting out, harvesting, and packaging) on adults 20 to 65 years of age. In the entire PFC, the oxy-HB concentration was significantly lower during planting out; however, it was the highest during sowing across the five horticultural activities ($P < 0.001$). In the right PFC, planting out yielded the lowest oxy-HB concentration, whereas sowing activities resulted in the highest oxy-HB concentration ($P < 0.01$). Within the left PFC, the oxy-HB concentration was the lowest during planting out and harvesting activities, and it was the highest during transplanting and sowing activities ($P < 0.001$).

During the planting out activity, during which participants transferred lettuce (*Lactuca sativa*) by hand to larger pots, the oxy-HB concentration was the lowest. This aligned with the findings of a previous visual stimulation study that indicated that the presence of plants in only 5% of the indoor space stimulates the autonomic nervous system, which is beneficial for psychophysiological stability (Park et al. 2016). Furthermore, a tactile stimulation study that used fNIRS and involved participants who touched the leaves of a plant (*Epipremnum aureum*) reported a decrease in the oxy-HB concentration in the PFC of participants (Koga and Iwasaki 2013). During the activity of mixing soil, the release of pleasant smells by nonpathogenic bacteria in the soil, such as *Mycobacterium vaccae*, resulted in the appearance of relative fast alpha and absolute spectral edge frequency 50 waves in the occipital cortex, indicating focused attention and a relaxed state. Moreover, previous olfactory stimulation research that involved increased levels of serotonin (5-hydroxytryptamine), which is a monoamine neurotransmitter, supported these findings (Kim et al. 2022).

Emotional assessments related to the presence of plants, such as transplanting and observing foliage, found significantly lower total mood disturbance scores when mood states were profiled and significantly increased scores for calming and stabilizing items evaluated using the semantic differential method (Park et al. 2019; Jung et al. 2017). These results support the findings of previous studies and suggest that stimuli from plants and natural substances provide emotional stability to individuals through multisensory stimulation. Therefore, formal planting out activities that involve simultaneous visual, tactile, and olfactory stimuli from plants can offer a more diverse range of stimuli than other activities, thus contributing to psychophysiological and psychological stability.

Across the five activities, the oxy-HB concentration was the highest during sowing. This finding is consistent with that of Techayusukcharoen et al. (2019), who found that tasks that involve brain activity, such as working memory, resulted in increased oxy-HB concentrations. Sowing is relatively labor-intensive and time-consuming and involves the use of tweezers. The use of tweezers during the task increased worker fatigue, leading to a higher oxy-HB concentration and PFC activation.

According to the theory of Petrides (1996), the PFC is functionally divided based on the characteristics of information processing. To examine the differences in activation levels between specific areas of the PFC during horticultural activities, our analysis focused on the differences in the oxy-HB concentrations recorded during these activities. Among the Brodmann areas used to classify the cerebral cortex, Brodmann area 10 is located in the anterior PFC and primarily regulates executive functions (planning, decision-making, and problem-solving), cognitive control (control of cognitive information, information processing, and conscious regulation), working memory, and planning (planning and inference for the future) (Ramnani and Owen 2004). Generally, the left hemisphere controls the right side of the body, language, classification abilities, and typical behavior, whereas the right hemisphere controls the response to emergencies, spatial organization, facial recognition, and emotion processing (MacNeilage et al. 2009). According to previous studies by Larson et al. (1995) and Miller and Cohen (2001), cortical activation occurs as task complexity increases. The PFC, through mutual connections with other brain areas, processes information and oversees functions such as response execution, memory retrieval, and emotional evaluation. However, in the current study, there were no significant differences between the left and right PFC, suggesting stabilization

Table 3. Oxyhemoglobin concentrations in the prefrontal cortex by horticultural activity (N = 39).

Agricultural activities	Entire PFC[i]	Right PFC[ii]	Left PFC[iii]
	Mean ± *SD* (mM)		
Sowing	(4.72 ± 8.22) × 10^{-4} c	(4.06 ± 8.69) × 10^{-4} bc	(4.91 ± 8.62) × 10^{-4} c
Transplanting	(2.54 ± 8.28) × 10^{-4} bc	(2.12 ± 8.9) × 10^{-4} bc	(2.49 ± 8.51) × 10^{-4} bc
Planting out	(−1.11 ± 7.94) × 10^{-4} a	(−1.76 ± 8.78) × 10^{-4} a	(−1.58 ± 8.3) × 10^{-4} a
Harvesting	(−1.11 ± 5.56) × 10^{-4} b	(−1.59 ± 5.63) × 10^{-4} b	(−1.11 ± 6.65) × 10^{-4} a
Packaging	(−0.19 ± 4.95) × 10^{-4} ab	(−0.01 ± 5.35) × 10^{-4} ab	(−0.51 ± 5.31) × 10^{-4} ab
F	5.493	4.178	5.245
P value	0.000***	0.003**	0.000***

[i] Entire PFC refers to channels 1 to 15 on NIRSIT Lite (OBELAB Inc.).
[ii] Right PFC refers to channels 1 to 7 on NIRSIT Lite (OBELAB Inc.).
[iii] Left PFC refers to channels 8 to 15 on NIRSIT Lite (OBELAB Inc.).
Post hoc analysis: a > b > c using Duncan's multiple range test.
, * significant at $P < 0.01$ and 0.001 using a one-way analysis of variance, respectively.
PFC = prefrontal cortex.

Table 4. Comparison of changes in the right prefrontal cortex and left prefrontal cortex oxyhemoglobin concentrations by horticultural activity (N = 39).

	Right PFC[i]	Left PFC[ii]		
Agricultural activities	Mean ± *SD* (mM)		*t*	*P* value
Sowing	$(4.07 \pm 8.69) \times 10^{-4}$	$(4.9 \pm 8.62) \times 10^{-4}$	−1.203	0.237^{NS}
Transplanting	$(2.12 \pm 8.90) \times 10^{-4}$	$(2.49 \pm 8.51) \times 10^{-4}$	−0.562	0.577^{NS}
Planting out	$(-1.76 \pm 8.78) \times 10^{-4}$	$(-1.58 \pm 8.3) \times 10^{-4}$	−0.249	0.805^{NS}
Harvesting	$(-1.59 \pm 5.63) \times 10^{-4}$	$(-1.15 \pm 6.65) \times 10^{-4}$	−0.610	0.545^{NS}
Packing	$(-0.01 \pm 5.35) \times 10^{-4}$	$(-0.51 \pm 5.31) \times 10^{-4}$	0.802	0.428^{NS}

[i] Left PFC refers to channels 8 to 15 on NIRSIT Lite (OBELAB Inc.).

[ii] Right PFC refers to channels 1 to 7 on NIRSIT Lite (OBELAB Inc.).

NS = nonsignificant at $P > 0.05$ using the paired *t* test; PFC = prefrontal cortex.

of the PFC. This finding implies that the five horticultural activities allowed cognitive, communicative, and emotional regulation and emotional recognition, thus providing an easily applicable approach with a broad range of effects for nature therapy.

A comparison of oxy-HB concentrations between sexes showed that oxy-HB concentrations were significantly lower during sowing and transplantation. This suggests that activities that involve relatively less physical effort, such as sowing and transplanting, result in lower oxy-HB concentrations than those of activities such as planting out, harvesting, and packaging. Harvesting and packaging activities showed minimal sex-related differences and low oxy-HB concentrations. This can be attributed to the fact that harvesting and packaging represent the final stages of horticultural activities, providing not only educational insights into crop growth and life but also the opportunity to obtain tangible outcomes (Kim et al. 2020, 2022; Lee et al. 2018b). Taken together, the results indicated that there were no significant sex-based differences during these activities.

Limitations. Although this study provides valuable insights into the impact of horticultural activities on PFC activation, several limitations should be noted. First, the study only measured changes in oxy-HB concentrations within the PFC; other brain regions were not considered. The PFC is known for its role in executive functions and cognitive control; however, activities that involve sensory and motor functions might also engage other regions such as the parietal lobes and motor cortex. Future research should include a comparative analysis of various brain regions to gain a comprehensive understanding of brain activity during horticultural tasks. Second, the sample size was limited, and the study population was restricted to adults 20 to 65 years of age. Studies that involve a larger and more diverse sample, including individuals with disabilities, could offer deeper insights into the therapeutic potential of horticultural activities with broader therapeutic applicability. Additionally, this study did not account for potential variations in individual baseline oxy-HB levels, which may have influenced the results. Baseline variability in neural activation can affect the interpretation of task-related changes in oxy-HB concentrations.

Conclusion

Our study demonstrated that different horticultural activities elicit distinct patterns of PFC activation. Sowing was associated with increased oxy-HB concentrations, whereas planting out was associated with decreased concentrations. These findings underscore the potential of horticultural activities to activate or stabilize brain functions, thus suggesting their applicability in therapeutic programs aimed at cognitive and psychological well-being. The incorporation of horticultural activities into therapeutic settings could be beneficial for individuals who seek to improve their mental health and cognitive function through natural and engaging activities. Future research should expand the scope of this study to include various brain regions and diverse populations to further elucidate the benefits of horticultural activities. Additionally, longitudinal studies could provide insights into the long-term effects of regular engagement in horticultural activities on brain function and mental health.

Table 5. Comparison of changes in oxyhemoglobin concentrations according to sex by horticultural activity.

	Entire PFC[i] (male participants = 15)	Entire PFC[i] (female participants = 24)		
Agricultural activities	Mean ± *SD* (mM)		*t*	*P* value
Sowing	$(8.44 \pm 0.01) \times 10^{-4}$	$(2.39 \pm 6) \times 10^{-4}$	2.115	0.023*
Transplanting	$(6.79 \pm 9.48) \times 10^{-4}$	$(-0.11 \pm 6.27) \times 10^{-4}$	2.744	0.009**
Planting out	$(0.35 \pm 0.56) \times 10^{-4}$	$(-2.77 \pm 5.69) \times 10^{-4}$	1.204	0.236^{NS}
Harvesting	$(-1.90 \pm 7.14) \times 10^{-4}$	$(-0.61 \pm 4.4) \times 10^{-4}$	−0.626	0.538^{NS}
Packing	$(0.28 \pm 5.2) \times 10^{-4}$	$(-0.5 \pm 4.87) \times 10^{-4}$	0.479	0.635^{NS}

[i] Entire PFC refers to channels 1 to 15 on NIRSIT Lite (OBELAB Inc.).

*, ** significant at $P < 0.05$ and $P < 0.01$ using the individual *t* test, respectively.

NS = nonsignificant at $P > 0.05$ using the paired *t* test; PFC = prefrontal cortex.

References Cited

Chang CY, Chen PK. 2005. Human response to window views and indoor plants in the workplace. HortScience. 40(5):1354–1359. https://doi.org/10.21273/HORTSCI.40.5.1354.

Choi JY, Park SA, Jung SJ, Lee JY, Son KC, An YJ, Lee SW. 2016. Physiological and psychological responses of humans to the index of greenness of an interior space. Complement Ther Med. 28:37–43. https://doi.org/10.1016/j.ctim.2016.08.002.

Dmochowski GM, Shereen AD, Berisha D, Dmochowski JP. 2020. Near-infrared light increases functional connectivity with a non-thermal mechanism. Cereb Cortex Commun. 1(1):tgaa004. https://doi.org/10.1093/texcom/tgaa004.

Ferrari M, Quaresima V. 2012. Brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application. Neuroimage. 63(2):921–935. https://doi.org/10.1016/j.neuroimage.2012.03.049.

Franco LS, Shanahan DF, Fuller RA. 2017. A Review of the benefits of nature experiences: More than meets the eye. Int J Environ Res Public Health. 14(8):864. https://doi.org/10.3390/ijerph14080864.

Haddad L, Schäfer A, Streit F, Lederbogen F, Grimm O, Wüst S, Deuschle M, Kirsch P, Tost H, Meyer-Lindenberg A. 2015. Brain structure correlates of urban upbringing, an environmental risk factor for schizophrenia. Schizophr Bull. 41(1):115–122. https://doi.org/10.1093/schbul/sbu072.

Hansen MM, Jones R, Tocchini K. 2017. Shinrin-Yoku (forest bathing) and nature therapy: A state-of-the-art review. Int J Environ Res Public Health. 14(8):851. https://doi.org/10.3390/ijerph14080851.

Hartig T, Evans GW, Jamner LD, Davis DS, Gärling T. 2003. Tracking restoration in natural and urban field settings. J Environ Psychol. 23(2):109–123. https://doi.org/10.1016/S0272-4944(02)00109-3.

Heckman MA, Weil J, De Mejia EG. 2010. Caffeine (1, 3, 7-trimethylxanthine) in foods: A comprehensive review on consumption, functionality, safety, and regulatory matters. J Food Sci. 75(3):77–87. https://doi.org/10.1111/j.1750-3841.2010.01561.x.

Hine R, Peacock J, Pretty J. 2008. Care farming in the UK: Contexts, benefits, and links with therapeutic communities. Ther Communities. 29:245–260. https://doi.org/10.1080/10937404.2016.1196155.

Igarashi M, Aga M, Ikei H, Namekawa T, Miyazaki Y. 2015. Physiological and psychological effects on high school students of viewing real and artificial pansies. Int J Environ Res Public Health. 12(3):2521–2531. https://doi.org/10.3390/ijerph120302521.

Jang TS, Yoon SJ. 2021. Hemodynamic analysis of the prefrontal cortex to verify the relationship between athlete performance level and auditory-spatial working memory: A functional near-infrared spectroscopy study. Exer Sci. 30:369–377. https://doi.org/10.15857/ksep.2021.30.3.369.

Jeong JE, Park SA. 2021. Physiological and psychological effects of visual stimulation with green plant types. IJERPH. 18(24):12932. https://doi.org/10.3390/ijerph182412932.

Jung SS, Park SA, Oh YA, Son KC. 2017. Horticultural therapy program based on health care education for stress eduction of hypertensive patients. J People Plants Environ. 20(2):125–134. https://doi.org/10.11628/ksppe.2017.20.2.125.

Kaplan S, Berman MG. 2010. Directed attention as a common resource for executive functioning and self-regulation. Perspect Psychol Sci. 5(1): 43–57. https://doi.org/10.1177/1745691609356784.

Kennedy C, Stewart ID, Ibrahim N, Facchini A, Mele R. 2014. Developing a multi-layered indicator set for urban metabolism studies in megacities. Ecol Ind. 47:7–15. https://doi.org/10.1016/j.ecolind.2014.07.039.

Kim JE, Ryu JS, Kim DS, Bae SJ. 2020. Relationship between types of self-care activities and demand of agro-healing services in adults with disabilities. Korean J Rural Planning. 26(03): 49–56. https://doi.org/10.7851/Ksrp.2020.26.3.049.

Kim SO, Son SY, Kim MJ, Lee CH, Park SA. 2022. Physiological responses of adults during soil-mixing activities based on the presence of soil microorganisms: A metabolomics approach. J Amer Soc Hort Sci. 147(3):135–144. https://doi.org/10.21273/JASHS05146-21.

Kim YJ, Kim SO, Choi NY, Ryu SH, Park SA. 2022. An awareness and demand survey on agro-healing among adults with symptoms of stress. J People Plants Environ. 25(4):385–399. https://doi.org/10.11628/ksppe.2022.25.4.385.

Koga K, Iwasaki Y. 2013. Psychological and physiological effect in humans of touching plant foliage - using the semantic differential method and cerebral activity as indicators. J Physiol Anthropol. 32(1):7. https://doi.org/10.1186/1880-6805-32-7.

Larson GE, Haier RJ, LaCasse L, Hazen K. 1995. Evaluation of a “mental effort” hypothesis for correlations between cortical metabolism and intelligence. Intelligence. 21(3):267–278. https://doi.org/10.1016/0160-2896(95)90017-9.

Lederbogen F, Kirsch P, Haddad L, Streit F, Tost H, Schuch P, Wüst S, Pruessner JC, Rietschel M, Deuschle M, Meyer-Lindenberg A. 2011. City living and urban upbringing affect neural social stress processing in humans. Nature. 474(7352):498–501. https://doi.org/10.1038/nature10190.

Lee AY, Kim SO, Park SA. 2021. Attention and emotional states during horticultural activities of adults in 20s using electroencephalography: A pilot study. Sustainability. 13(23):12968. https://doi.org/10.3390/su132312968.

Lee SS, Park SA, Kwon OY, Song JE, Son KC. 2012. Measuring range of motion and muscle activation of flower arrangement tasks and application for improving upper limb function. Korean J Hortic Sci Technol. 30(4):449–462. https://doi.org/10.7235/hort.2012.12071.

Lee AY, Park SA, Moon YJ, Son KC. 2018a. Kinematic and kinetic analysis of horticultural activities for postural control and balance training. HortScience. 53(10):1541–1552. https://doi.org/10.21273/HORTSCI13361-18.

Lee AY, Park SA, Park HG, Son KC. 2018b. Determining the effects of a horticultural therapy program for improving the upper limb function and balance ability of stroke patients. HortScience. 53(1):110–119. https://doi.org/10.21273/HORTSCI12639-17.

MacNeilage PF, Rogers LJ, Vallortigara G. 2009. Origins of the left & right brain. Sci Am. 301(1):60–67. https://doi.org/10.1038/scientificamerican0709-60.

Miller EK, Cohen JD. 2001. An integrative theory of prefrontal cortex function. Annu Rev Neurosci. 24:167–202. https://doi.org/10.1146/annurev.neuro.24.1.167.

National Institute of Horticultural and Herbal Science. 2018. A tendency analysis on methodological effectiveness of Agro-healing based care farming in Europe. https://scienceon.kisti.re.kr/commons/util/originalView.do?dbt=TRKO&cn=TRKO201800043730.

Oh YA, Kim SO, Park SA. 2019a. Real foliage plants as visual stimuli to improve concentration and attention in elementary students. Int J Environ Res Public Health. 16(5):796. https://doi.org/10.3390/ijerph16050796.

Oh YA, Kim YS, Park SA. 2019b. Analysis of the emotional effects of horticultural experience program based on social emotional learning theory in elementary school students. Korean J Rural Planning. 25(04):87–97. https://doi.org/10.7851/Ksrp.2019.25.4.087.

Ohly H, White MP, Wheeler BW, Bethel A, Ukoumunne OC, Nikolaou V, Garside R. 2016. Attention restoration theory: A systematic review of the attention restoration potential of exposure to natural environments. J Toxicol Environ Health B Crit Rev. 19(7):305–343. https://doi.org/10.1080/10937404.2016.1196155.

Park SA, Shoemaker CA, Haub MD. 2009. Physical and psychological health conditions of older adults classified as gardeners or nongardeners. HortScience. 44(1):206–210. https://doi.org/10.21273/HORTSCI.44.1.206.

Park SA, Song C, Choi JY, Son KC, Miyazaki Y. 2016. Foliage plants cause physiological and psychological relaxation as evidenced by measurements of prefrontal cortex activity and profile of mood states. HortScience. 51(10): 1308–1312. https://doi.org/10.21273/HORTSCI11104-16.

Park SA, Lee AY, Park HG, Lee WL. 2019. Benefits of gardening activities for cognitive function according to measurement of brain nerve growth factor levels. Int J Environ Res Public Health. 16(5):760. https://doi.org/10.3390/ijerph1605076.

Petrides M. 1996. Specialized systems for the processing of mnemonic information within the primate frontal cortex. Philos Trans R Soc Lond B Biol Sci. 351(1346):1455–1462. https://doi.org/10.1098/rstb.1996.0130.

Ramnani N, Owen AM. 2004. Anterior prefrontal cortex: Insights into function from anatomy and neuroimaging. Nat Rev Neurosci. 5(3): 184–194. https://doi.org/10.1038/nrn1343.

Son KC, Song JE, Um SJ, Lee JS, Kwack HR. 2004. Effects of visual recognition of green plants on the changes of EEG in patients with schizophrenia. Acta Hortic. 639:193–199. https://doi.org/10.17660/ActaHortic.2004.639.24.

Song C, Ikei H, Miyazaki Y. 2016. Physiological effects of nature therapy: A review of the research in Japan. Int J Environ Res Public Health. 13(8):781. https://doi.org/10.3390/ijerph13080781.

Tarkka IM, Hallett M. 1990. Cortical topography of premotor and motor potentials preceding self-paced, voluntary movement of dominant and non-dominant hands. Electroencephalogr Clin Neurophysiol. 75(2):36–43. https://doi.org/10.1016/0013-4694(90)90150-I.

Techayusukcharoen R, Iida S, Aoki C. 2019. Observing brain function via functional near-infrared spectroscopy during cognitive program training (dual task) in young people. J Phys Ther Sci. 31(7):550–555. https://doi.org/10.1589/jpts.31.550.