Electromyographic Analysis of Upper- and Lower-extremity Muscles in Adults during Agro-healing Activities

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KEYWORDS. animal-assisted activity, care farm, gardening, horticulture, pet therapy, plant-mediated activity

ABSTRACT. This study investigated the activity of upper- and lower-extremity muscles for 15 agricultural tasks of agro-healing. For the development of an agro-healing program using farm resource types, 15 selected agro-healing activities (namely, digging, raking, fertilizing, planting transplants, tying plants to stakes, watering, harvesting, washing, cutting, cooking, collecting natural objects, decorating natural objects, interacting with dogs, walking dogs, and feeding fish) were extracted and performed in a total of 21 adults (average age: 42.29 ± 14.76 years) at D Care Farm in Cheongju, Korea, from June to July 2022. Before these activities, informed consent was obtained from participants and muscle activity of the upper and lower extremities was measured. Muscle activation during activity performance was measured using electromyography (EMG), and the rating of perceived exertion for each activity was investigated. Bipolar surface EMG electrodes were attached at 16 locations on the left and right upper-extremity muscles (anterior deltoid, biceps brachialis, brachioradialis, and flexor carpi ulnaris) and lower-extremity muscles (vastus lateralis, vastus medialis, biceps femoris, and gastrocnemius). The results indicated that the activity of the lower-extremity muscles was higher than that of the upper-extremity muscles during 15 agricultural activities. During plant-mediated activity and animal-assisted activities, the rate of right muscle use was higher than that of left muscle use among the upper-extremity muscles, whereas the rate of right and left muscle use showed a similar tendency among the lower-extremity muscles. During plant-mediated activities, agricultural activities involving the use of heavy tools highly activated the right forearm muscle (flexor carpi ulnaris), whereas holding and interacting with animals highly activated the left forearm muscles (biceps brachialis, brachioradialis, and flexor carpi ulnaris). It is expected that the EMG data obtained in this study can be used as basic biomechanical data when designing an agro-healing program to improve physical function.

Agriculture is not limited to the first, second, and third industries that produce, process, and distribute crops. In particular, agriculture is being converted into new types of industries, such as agro-healing, care farming, social farming, and green care farming, and is being used as a solution to social problems by maintaining and promoting health.

Agro-healing refers to "The industry that creates social or economic value through the utilization of various agricultural and rural resources to promote the recovery, maintenance, and promotion of people's health and related activities." Agro-healing is a rapidly growing form of social agriculture in which rural resources are being used for healing and restoration (Hassink and Van Dijk 2006). Agro-healing can be defined as the use of agriculture to provide healing. Depending on the various programs and means included in healing activities, they can be divided into horticultural therapy, animal therapy, agricultural therapy, wilderness therapy, and ecological therapy; these can be integrated and understood as green care farming (Sempik et al. 2010). Generally, it involves activities for preventive healing, rather than treatment, which promotes physical and mental healing (Hassink et al. 2007). In addition to the specific benefits of agro-healing, participation in an agro-healing program can support resilience, as well as the adoption and development of long-term healthy and sustainable lifestyle choices. Although several previous studies have reported the positive effects of agro-healing on psychological, social, cognitive, and physical health, studies investigating the healing mechanisms of agricultural activity and agricultural environmental resources remain lacking (Relf 2006; Rural Development Administration 2018).

Horticulture is an agricultural activity involving cultivation of fruits, vegetables, and flowers (Ferrini 2003; Park et al. 2022). Horticultural activities can serve as weight-bearing exercises that use all muscles of the hand, upper extremities, and lower extremities and can be applied as treatment for patients with physical disabilities, such as the elderly and hemiplegic patients with disabilities (Park et al. 2014a, 2015). The healing mechanisms of physical activities on muscles have been investigated. In particular, previous reports suggested that all actions involving digging the ground, sowing seeds, watering, and pulling weeds during horticultural activities were accompanied by physical activities and showed that medium-intensity [3.5–5.5 metabolic equivalent of task (METs)] to high-intensity (6.2–6.6 METs) physical activities had an effect on elementary school students and adults (Park et al. 2012a, 2013a), whereas low-intensity (1.7–2.9 METs) to moderate-intensity (3.0–4.5 METs) physical activities had an effect on the elderly (Park et al. 2008, 2011, 2012b). In addition, activities such as digging, raking, soil mixing, pulling weeds, and hoeing highly activated the right carpal flexor and brachial radial muscles among the 16 upper- and lower-extremity muscles, and eight flower arrangement activities for physical rehabilitation activated the upper-extremity muscles (Lee et al. 2012; Park et al. 2014a). Nonetheless, studies on muscle activity using horticultural activities have been limited to general adults, the elderly, hemiplegic patients with disabilities, and individuals undergoing upper-extremity rehabilitation. Furthermore, reports on upper- and lower-extremity muscle activity targeting agro-healing physical activities in farms are lacking.

Activities assisted by animals and insects have various positive effects in agro-healing sites. Many animals have a warm body temperature, soft fur, and tails that show emotion, and interactions with them are characterized by excellent communication through mutual reactions with the participants. Interacting with animals improves medical and sensory issues by increasing relaxation, stress relief, communication, and physical activity (Rural Development Administration 2018; Cole and Gawlinski 1995). Nevertheless, existing research on therapeutic agricultural interventions for improving physical health is minimal.

EMG measures muscle activity using EMG signals collected through attached electrodes on the skin surface (De Luca 1997; Kim 2000). Skin surface electrodes, which are placed on the skin in the form of disc-shaped silver plates or tin connected to wires to measure nerve and muscle activity, have the advantage of being able to examine muscle activity for a long period without being inserted into the muscle (Kim 2000). A previous study on a healing mechanism using EMG reported that flower arrangement work, indoor gardening activities, gardening, etc., could be used as a horticultural therapy intervention for physical health and rehabilitation (Lee et al. 2012, 2016, 2018; Park et al. 2014b, 2015). Nevertheless, no study has yet investigated the movement and activation of muscles using agricultural work.

This study provided EMG data during various agricultural work activities and sought to use them as basic data on the biomechanical stimulation effect when designing an agro-healing program to improve physical function and mental health.

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Materials and methods

Research participants. Adult male and female participants aged ≥20 years who voluntarily participated in agro-healing activities were recruited via promotional documents that were attached at apartment management offices and universities surrounding the D Care Farm in Cheongju, Korea. The inclusion criteria for participation were as follows: age in their 20s or older, no physical activity for 24 h before testing, and access to proper clothing and shoes for agricultural activities (Park et al. 2013b). Participants visited the farm once and randomly performed 15 agro-healing activities and measured their EMG. Each activity was performed for 3 min followed by 30 s of rest.

The researcher explained the purpose of the study and precautions for performing agricultural activities to the participants, and informed consent was obtained from the participating adults before their inclusion in the study. The average age, height, weight, and body mass index of the participants were 42.29 ± 14.76 years, 165.67 ± 7.35 cm, 63.32 ± 10.35 kg, and 22.97 ± 2.76 kg·m^{-2}, respectively, and all were right-handed (Table 1). This study was approved by the Institutional Bioresearch Ethics Board of Konkuk University (7001355–202204-HR-546).

Selection of detailed agro-healing activities. The resource type of farm agro-healing services was divided into plant- and animal-mediated activities, and 15 detailed activities were subdivided into work processes in order for the participants to perform them in the same manner (Lee et al. 2012; Park et al. 2014a). The 15 detailed actions were as follows: digging, raking, fertilizing, planting transplants, tying plants to stakes, watering, harvesting, washing, cutting, cooking, collecting natural objects, decorating natural objects, interacting with dogs, walking dogs, and feeding fish (Table 2). The biomechanical effect was measured after 21 participants performed healing activities in a previously prepared Farm D.

Measurements. Agro-healing upper- and lower-extremity muscle activities were measured using a 16-channel wireless surface EMG system (Ultium EMG; Noraxon Inc., Scottsdale, AZ, USA). The skin surface was wiped with rubbing alcohol to reduce skin resistance to signals, and surface electrodes were attached to 16 muscles. EMG patches were attached at the following 16 sites on the upper and lower extremities based on the results of previous studies: right anterior deltoid (ANT. DELTOID. RT), left anterior deltoid (ANT. DELTOID. LT), right biceps brachialis (BICEPS. BR. RT), left biceps brachialis (BICEPS. BR. LT), right brachioradialis (BRACHIORAD. RT), left brachioradialis (BRACHIORAD. LT), right flexor carpi ulnaris (FLEX. CARP. R. RT), left flexor carpi ulnaris (FLEX. CARP. R. LT), right vastus lateralis (VLO. RT), left vastus lateralis (VLO. LT), right vastus medialis (VMO. RT), left vastus medialis (VMO. LT), right biceps femoris (BICEPS. FEM. RT), left biceps femoris (BICEPS. FEM. LT), right gastrocnemius (MED. GASTRO. RT), and left gastrocnemius (MED. GASTRO. LT) (Park et al. 2014b) (Fig. 1). For the measurement of upper and lower limb muscle movements during work using EMG, 30-second rest was allowed between activities after performing the garden activity, and the activities were conducted in a random order (Park et al. 2013b). The EMG system collected 16-channel data at a sampling

Table 1. Study participants were recruited to analyze upper and lower limb muscle movements using electromyography during 15 agro-healing tasks (N = 21).

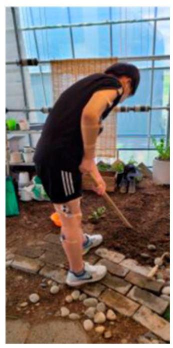
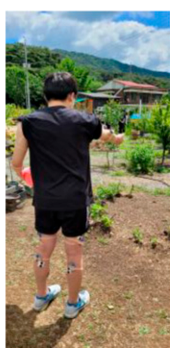
	Male (n = 6)	Female (n = 15)	Total (N = 21)
Variable	Mean ± *SD*		
Age (years)	35.33 ± 17.47	45.07 ± 13.74	42.29 ± 14.76
Height (cm)[i]	172.50 ± 5.75	151.98 ± 42.07	165.67 ± 7.35
Body weight (kg)[ii]	70.75 ± 8.44	60.35 ± 10.10	63.32 ± 10.35
Body mass index (kg·m^{-2})[iii]	23.74 ± 2.23	22.66 ± 3.04	22.97 ± 2.76
Dominant hand			Right-handed

[i] Height was measured using an anthropometer (Ok7979; Samhwa, Seoul, South Korea) without shoes. 1 cm = 0.3937 inch.

[ii] Body weight was measured using a body fat analyzer (ioi 353; Jawon Medical, Gyeongsan, South Korea). 1 kg = 2.2046 lb.

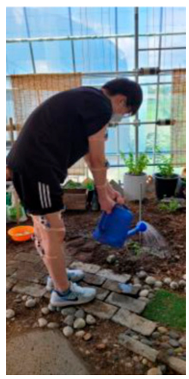
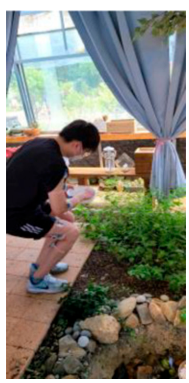
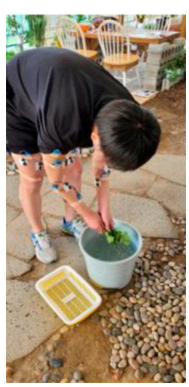
[iii] Body mass index was calculated using the following formula: [weight (kg)]/[height (m)^2]. 1 kg·m^{-2} = 0.2048 lb/ft^2.

Table 2. **Detailed descriptions of the 15 tasks used for performing upper and lower limb electromyography during agro-healing activities. All participants visited the farm once and performed agro-healing activities according to the instructions.**

Resource type	Motion method	Descriptions[i]
Plant-mediated activity		
Digging		1) Hold the Korean hand plow in your right hand. 2) Squat down with your legs shoulder-width apart. 3) Move your right foot one step forward. 4) Insert the blade into the designated space as much as possible with the right hand holding the Korean hand plow. 5) Dig up the soil. 6) Stand straight with your legs together and looking straight ahead.
Raking		1) Spread your feet shoulder-width apart and hold a Korean hand plow with both hands, with the wide side facing the ground. 2) Step forward one step and grab the one-third point of the handle. 3) Extend your arms and put the Korean hand plow on the ground. 4) Scrape up the soil and bring it in front of you. 5) Place your feet properly. 6) Look straight ahead and stand upright.
Fertilizing		1) Stand with your feet shoulder-width apart and hold a bowl of manure with your left arm. 2) Hold a handful of base manure with your right hand. 3) Bend your back and extend your right arm forward to sprinkle manure in the designated area. 4) Look straight ahead and stand upright.
Planting transplants		1) Hold the trowel handle with your right hand. 2) Squat down. 3) Insert the trowel in the designated area. 4) Dig up the soil and pile it up to the right. 5) Plant the seedlings with both hands. 6) Cover with a trowel. 7) Stand straight looking straight ahead.

(Continued on next page)

Table 2. (*Continued*)

Resource type	Motion method	Descriptions[i]
Tying plants to stakes		1) Stand with your feet shoulder-width apart. 2) Sit with both legs bent horizontally. 3) Using both hands, insert the support next to the plant. 4) Use both hands to tie the holding string. 5) Stand straight looking straight ahead.
Watering		1) Prepare a water tank with 2 L of water. 2) Hold the water tank with both hands. 3) Sprinkle water around the plants. 4) Adjust the height and water up and down. 5) Stand straight looking straight ahead.
Harvesting		1) Stand holding a basket with your left hand. 2) Move after checking the location of the plants in the harvesting stage of the garden. 3) Lower your back. 4) Extend your right hand to pick a plant leaf. 5) Bring your outstretched hand toward your body and put it in the basket three times. 6) Stand straight looking straight ahead.
Washing		1) Stand holding a basket of harvest with both hands. 2) Go to faucet. 3) Wash the harvested lettuce under running water with both hands. 4) Put the washed lettuce into a bowl. 5) Stand straight looking straight ahead.

(*Continued on next page*)

Table 2. (*Continued*)

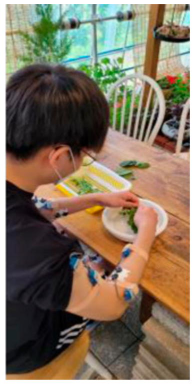
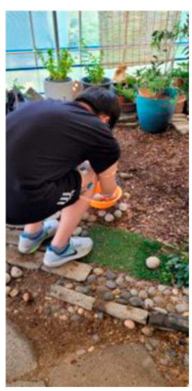
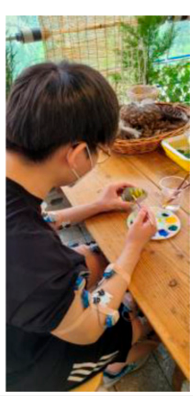
Resource type	Motion method	Descriptions[i]
Cutting		1) Sit down and hold five lettuce leaves with both hands. 2) Tear finely 10 times. 3) Put them in the basket. 4) Look straight ahead and stand upright.
Cooking		1) Sit down and scoop rice into the rice bowl five times with a spoon. 2) Put the cut lettuce on top. 3) Squeeze the tube of red pepper paste. 4) Mix five times using a spoon. 5) Stand upright looking straight ahead.
Collecting natural objects		1) Stand holding a basket with your left hand. 2) Go to an outdoor farm. 3) Lower your back. 4) Extend your right hand to catch a natural object. 5) Bring your outstretched hand toward your body and straighten your back. 6) Put three in the basket held in the left hand. 7) Stand straight looking straight ahead.
Decorating natural objects		1) Sit on a chair in front of the table, extend your left hand, and pick up a natural object in a basket and bring it toward your body. 2) Extend your right hand and bring the paint to the brush toward your body. 3) Paint a natural object (stone) three times. 4) Stand straight looking straight ahead.

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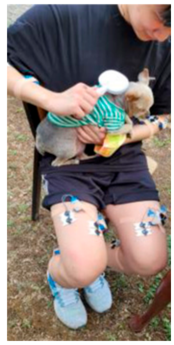
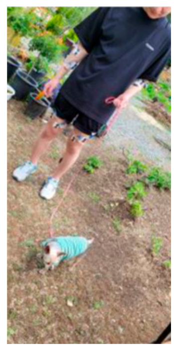
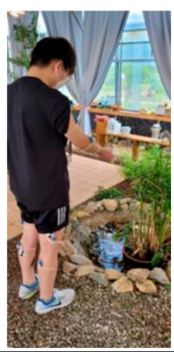
Table 2. (*Continued*)

Resource type	Motion method	Descriptions[i]
Animal-assisted activity		
Interacting with dogs		1) Sit down and hold your pet with your left hand. 2) Hold the comb with your right hand. 3) Brush the pet's back three times. 4) Stand straight looking straight ahead.
Walking the dog		1) Stand holding the lead rope with your left hand. 2) Squat down. 3) Put your pet on a lead leash. 4) Stand up. 5) Walk three times around the designated farm garden.
Feeding the fish		1) Bend your back in a straight posture. 2) Extend your right hand to catch the feeding bowl on the floor. 3) Look at the pond fish. 4) Go to the pond. 5) Crouch down to catch prey. 6) Stand straight looking straight ahead.

[i] All participants applied the electromyography patch and repeated the same instructions. Participants were required to repeat each activity for 3 min followed by 30 s of rest. The 15 agricultural activities were performed in a random order, and electromyograms were obtained continuously during one visit to the farm.

frequency of 2000 Hz and a bandwidth of 10 to 500 Hz. According to previous studies, normalization of EMG data is necessary when electrodes are applied to different muscles and individuals because technical, anatomical, and physiological factors can affect the EMG magnitude (Burden 2010; Cram et al. 1998; Park et al. 2014b). Hence, in this study, EMG data were normalized after measurement to %reference voluntary contraction (%RVC) using the peak of RVC motion.

After EMG measurement, the psychological motor emotions during agro-healing activities were assessed using the rating of perceived exertion (RPE) scale developed by Borg (1973). The RPE scale evaluates the subjective exercise intensity that appears as a result of the integration of local sensations from the respiratory, circulatory, metabolic, and skeletal muscle systems, as well as peripheral parts (Kim et al. 1997). The RPE scale evaluates low-intensity exercise intensity as "not difficult" (RPE 6–11), medium-intensity exercise intensity as "slightly difficult" (RPE 12–13), and high-intensity exercise intensity as "tough" (RPE 15–16). The RPE scale is a valuable tool for assessing exercise performance and plays an important role in clinical diagnosis, exercise prescription, and evaluation of exercise ability (Borg 1973; Kim et al. 2006).

Data analysis. For the analysis of the demographic data and subjective exercise intensity of the participants, descriptive statistics were calculated using Microsoft Excel (Office 2020; Microsoft Corp., Redmond, WA, USA) for the average, standard deviation, and percentage of each item. In this study, all raw EMG data were converted to integrated EMG (IEMG) data using MyoResearch XP Master (MyoResearch XP Clinical Edition 1.07; Noraxon) to process the signals (Lee et al. 2016, 2018; Park et al. 2014b). The EMG signals (sampling rate, 2000 Hz) were rectified to calculate the mean, maximum, and IEMG values of the amplitude. Noise was removed by cutting

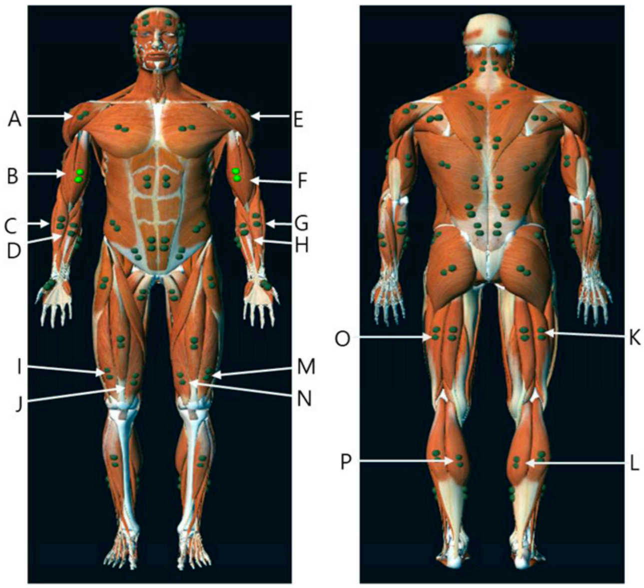


Fig. 1. Positions of 16 muscles attached for upper- and lower-extremity electromyography (EMG) analysis during agro-healing activities. EMG patches were attached to a total of 16 areas of the upper and lower extremities by referring to the results of previous studies (Park et al. 2014b); (A, ANT.DELTOID.RT) right anterior deltoid, (B, BICEPS.BR.RT) right biceps brachialis, (C, BRACHIORAD.RT) right brachioradialis, (D, FLEX.CARP.R.RT) right flexor carpi ulnaris, (E, ANT.DELTOID.LT) left anterior deltoid, (F, BICEPS.BR.LT) left biceps brachialis, (G, BRACHIORAD.LT) left brachioradialis, (H, FLEX.CARP.R.LT) left flexor carpi ulnaris, (I, VLO.RT) right vastus lateralis, (J, VMO.RT) right vastus medialis, (K, BICEPS.FEM.RT) right biceps femoris, (L, MED.GASTRO.RT) right gastrocnemius, (M, VLO.LT) left vastus lateralis, (N, VMO.LT) left vastus medialis, (O, BICEPS.FEM.LT) left biceps femoris, (P, MED.GASTRO.LT) left gastrocnemius.

the low (10 Hz) and high (250 Hz) frequencies. The IEMG is recommended as the preferred method for describing muscle activation using surface EMG (Kim et al. 2013; Lee et al. 2016, 2018; Morey-Klapsing et al. 2004), and EMG amplitude data could be normalized using the amplitude measured during the maximum voluntary contraction (MVC) of the targeted muscles (Mathiassen et al. 1995). Thus, the MVC of the selected muscles was measured in each participant using a previously described method (Lee et al. 2016, 2018; Park et al. 2014b). The MVC value was set to 100%, which was used to standardize the muscle activity values during horticultural activities (%MVC IEMG). Comparative analysis of muscle activity with %MVC IEMG was performed using one-way analysis of variance with SPSS version 25 for Windows (IBM Corp., Armonk, NY, USA), followed by Duncan's post hoc test. All statistical significance levels were set at $P < 0.05$.

Results

Demographic characteristics. This study was conducted on a total of 21 adults (6 men [28.6%] and 15 women [71.4%]). With respect to their final education level, 71.5% had a university degree. Furthermore, 71.4% had a job, whereas 28.6% were unemployed.

Movement of the upper- and lower-extremity muscles during agro-healing activities. As a result of examining the muscle activity during the 15 agricultural activities, all 16 upper- and lower-extremity muscles were used. The activity of the lower-extremity muscles was higher than that of the upper-extremity muscles. The bilateral upper-extremity muscles (namely, the biceps brachialis, brachioradialis, and flexor carpi ulnaris) and lower-extremity muscles (namely, vastus lateralis, vastus medialis, biceps femoris, and gastrocnemius) showed significant results ($P < 0.001$; Table 3). Among the upper-extremity muscles, the right muscles were used more frequently than the left muscles. The lower-extremity muscles tended to have a higher EMG ratio for the left muscles than that for the right muscles.

The muscle activity of subjects by age was investigated while performing 15 agricultural activities. In the upper limb muscle activity analysis of adults in their 20s and 30s during agro-healing activities, the flexor carpi ulnaris showed the highest muscle activity in plant-mediated activities, and the biceps brachialis showed the highest muscle activity in animal-assisted activities. According to lower limb muscle activity analysis, all muscles were used evenly during plant-mediated activities, whereas right muscles showed higher activity during animal-assisted activities. In addition, when comparing the muscles of the upper and lower limbs, the activity of the lower limb muscles was found to be higher, and all regions showed significant results (Table 4). In upper limb muscle activity analysis of adults in their 40s and 50s, the flexor carpi ulnaris showed the highest muscle activity during plant-assisted activities, and the biceps brachialis and flexor carpi ulnaris showed the highest muscle activity during animal-assisted activities. According to the lower limb muscle activity analysis, vastus lateralis and vastus medialis showed high muscle activity in plant-mediated and animal-assisted activities (Table 5).

The upper-extremity muscle activity during the 15 agricultural activities was categorized into plant- and animal-mediated activities and was examined. Table 6 presents the results of activity analysis for the eight upper-extremity muscles using core resources after agricultural work.

Among plant-mediated activities, muscle activity was significant during digging, raking, fertilizing, planting transplants, tying plants to stakes, harvesting, cutting, and cooking ($P < 0.001$). The raking motion (defined as the motion of raking up the soil with a pronged rake with both hands using the left and right muscles evenly) had the highest muscle activity among the plant-mediated activities. The post hoc test showed that the flexor carpi ulnaris on both sides was the most frequently used muscle. Among the eight upper-extremity muscles, the right flexor carpi ulnaris exhibited the highest activity during digging, raking, planting transplants, tying plants to stakes, watering,

Table 3. Muscle activation data for 16 muscles of the upper and lower extremities during the 15 agro-healing activities. The table shows muscle activity in plant-mediated activities and animal-assisted activities (N = 21). lt = left; rt = right.

	Maximum voluntary contraction integrated electromyography [mean (*SD*)][i]					
	Plant-mediated activity		Animal-assisted activity		Total activity	
Variable	Total	*P* value	Total	*P* value	Total	*P* value
Upper limb muscles						
Anterior deltoid rt	15.51 (14.17)	0.050	12.85 (17.13)	0.003**	14.98 (14.82)	0.011*[ii]
Biceps brachialis rt	16.23 (11.58)	0.029*	14.19 (11.36)	<0.001***	15.82 (11.55)	<0.001***
Brachioradialis rt	11.25 (10.18)	0.002**	7.66 (6.62)	<0.001***	10.53 (9.67)	<0.001***
Flexor carpi ulnaris rt	28.10 (21.76)	<0.001***	17.34 (18.01)	<0.001***	25.95 (21.47	<0.001***
Anterior deltoid lt	15.99 (40.30)	0.345	6.22 (6.70)	<0.001***	14.03 (36.37)	0.014*
Biceps brachialis lt	13.41 (12.46)	<0.001***	15.10 (24.93)	0.001**	13.75 (15.72)	<0.001***
Brachioradialis lt	9.60 (7.50)	<0.001***	9.09 (13.52)	<0.001***	9.50 (9.01)	<0.001***
Flexor carpi ulnaris lt	23.57 (19.59)	<0.001***	17.36 (18.40)	<0.001***	22.33 (19.49)	<0.001***
Lower-extremity muscles						
Vastus lateralis rt	29.90 (28.42)	<0.001***	13.60 (14.26)	<0.001***	26.64 (26.99)	<0.001***[ii]
Vastus medialis rt	34.62 (38.63)	<0.001***	13.59 (19.31)	<0.001***	30.41 (36.57)	<0.001***
Biceps femoris rt	19.47 (16.76)	<0.001***	13.84 (12.84)	<0.001***	18.35 (16.19)	<0.001***
Gastrocnemius rt	20.53 (19.84)	<0.001***	20.41 (23.68)	0.001**	20.50 (20.62)	<0.001***
Vastus lateralis lt	32.16 (33.09)	<0.001***	16.14 (16.82)	<0.001***	28.96 (31.18)	<0.001***
Vastus medialis lt	35.35 (37.77)	<0.001***	17.66 (25.99)	0.001**	31.81 (36.39)	<0.001***
Biceps femoris lt	21.05 (21.17)	<0.001***	14.97 (18.58)	0.261	19.83 (20.79)	<0.001***
Gastrocnemius lt	20.58 (15.99)	<0.001***	18.78 (13.65)	<0.001***	20.22 (15.55)	<0.001***

[i] Values are expressed as means (*SD*). Means (*SD*) are expressed as percentages of the recorded maximum voluntary contraction of each muscle (% of maximum voluntary contraction integrated electromyography).
[ii] *, **, *** indicate significant at $P < 0.05$, 0.01, or 0.001, respectively, by ANOVA.

harvesting, washing, cutting, and cooking, whereas the left flexor carpi ulnaris displayed the highest activity during fertilizing, tying plants to stakes, watering, and decorating natural objects. In addition, washing, collecting natural objects, and decorating natural objects significantly used the least amount of muscles among the upper-extremity muscles.

Among animal-assisted activities, interacting with dogs, walking dogs,

Table 4. Electromyography data of upper and lower limb muscles of adults in their 20s and 30s when performing the 15 agro-healing activities (n = 9). lt = left; rt = right.

	Maximum voluntary contraction integrated electromyography [mean (*SD*)][i]					
	Plant-mediated activity		Animal-assisted activity		Total activity	
Variable	Total	*P* value	Total	*P* value	Total	*P* value
Upper limb muscles						
Anterior deltoid rt	15.92 (19.3)	0.334	15.21 (24.97)	0.295	15.78 (20.45)	0.394[ii]
Biceps brachialis rt	15.00 (11.23)	0.13	12.59 (9.58)	0.001**	14.51 (10.93)	0.014*
Brachioradialis rt	10.81 (9.16)	0.117	7.66 (6.62)	0.011*	10.13 (8.64)	0.025*
Flexor carpi ulnaris rt	24.67 (20.13)	<0.001***	15.37 (18.13)	0.047*	23.23 (20.71)	<0.001***
Anterior deltoid lt	11.69 (9.9)	<0.001***	5.54 (7.13)	0.018*	10.45 (9.71)	<0.001***
Biceps brachialis lt	10.71 (9.13)	0.023*	8.60 (8.85)	<0.001***	10.29 (9.08)	0.001**
Brachioradialis lt	7.68 (5.13)	0.003**	12.59 (9.58)	0.001**	7.38 (5.47)	<0.001***
Flexor carpi ulnaris lt	20.89 (16.64)	<0.001***	17.48 (22.34)	0.015*	19.78 (17.03)	<0.001***
Lower-extremity muscles						
Vastus lateralis rt	26.60 (27.20)	<0.001***	9.35 (7.81)	0.001**	23.15 (25.51)	<0.001***[ii]
Vastus medialis rt	33.23 (36.14)	<0.001***	13.62 (25.38)	0.038*	29.31 (35.07)	<0.001***
Biceps femoris rt	18.45 (12.18)	<0.001***	12.07 (7.59)	<0.001***	17.17 (11.67)	<0.001***
Gastrocnemius rt	24.16 (22.92)	<0.001***	20.91 (22.64)	0.007**	23.51 (22.81)	<0.001***
Vastus lateralis lt	26.09 (25.19)	<0.001***	9.10 (7.63)	0.017*	22.69 (23.76)	<0.001***
Vastus medialis lt	31.16 (35.58)	<0.001***	10.28 (9.44)	0.053	26.98 (33.14)	<0.001***
Biceps femoris lt	17.63 (17.35)	0.018**	12.59 (19.88)	0.675	16.61 (17.92)	0.047*
Gastrocnemius lt	22.53 (18.86)	<0.001***	17.49 (12.4)	<0.001***	21.52 (17.83)	<0.001***

[i] Values are expressed as means (*SD*). Means (*SD*) are expressed as percentages of the recorded maximum voluntary contraction of each muscle (% of maximum voluntary contraction integrated electromyography).
[ii] *, **, *** indicate significant at $P < 0.05$, 0.01, or 0.001, respectively, by ANOVA.

Table 5. Electromyography data of upper and lower limb muscles of adults in their 40s and 50s when performing the 15 agro-healing activities (n = 8). lt = left; rt = right.

	Maximum voluntary contraction integrated electromyography [mean (*SD*)][i]					
	Plant-mediated activity		Animal-assisted activity		Total activity	
Variable	Total	*P* value	Total	*P* value	Total	*P* value
Upper limb muscles						
Anterior deltoid rt	14.62 (8.27)	0.012*	9.77 (5.89)	0.001**	13.65 (8.07)	<0.001***[ii]
Biceps brachialis rt	17.53 (11.02)	0.576	14.34 (10.05)	<0.001***	16.89 (10.87)	0.025**
Brachioradialis rt	11.98 (12.45)	0.536	7.85 (8.51)	0.094	11.16 (11.85)	0.321
Flexor carpi ulnaris rt	37.41 (23.58)	<0.001***	21.5 (15.70)	<0.001***	34.23 (23.08)	<0.001***
Anterior deltoid lt	20.31 (63.5)	0.598	6.67 (6.45)	0.003**	17.58 (57.07)	0.547
Biceps brachialis lt	13.21 (9.31)	0.039*	13.16 (12.55)	<0.001***	13.20 (9.97)	<0.001***
Brachioradialis lt	12.40 (9.42)	0.245	13.45 (19.73)	0.009**	12.61 (12.09)	0.003**
Flexor carpi ulnaris lt	28.1 (20.52)	<0.001***	20.17 (19.99)	<0.001***	26.52 (20.58)	<0.001***
Lower-extremity muscles						
Vastus lateralis rt	36.25 (32.49)	<0.001***	19.43 (19.31)	<0.001***	32.88 (30.99)	<0.001***
Vastus medialis rt	40.69 (46.41)	<0.001***	15.67 (14.69)	0.001**	35.69 (43.16)	<0.001***
Biceps femoris rt	21.34 (22.71)	0.046*	13.74 (16.48)	0.086	19.82 (21.76)	0.018*
Gastrocnemius rt	19.08 (19.32)	0.075	23.08 (29.41)	0.137	19.88 (21.63)	0.063
Vastus lateralis lt	40.44 (41.56)	<0.001***	21.31 (18.76)	0.007*	36.61 (38.81)	<0.001***
Vastus medialis lt	39.78 (39.91)	<0.001***	18.14 (15.24)	0.002**	35.45 (37.31)	<0.001***
Biceps femoris lt	26.99 (26.92)	0.017*	18.16 (20.47)	0.092	25.23 (25.92)	0.006**
Gastrocnemius lt	19.10 (13.86)	<0.001***	19.92 (15.14)	0.002**	19.27 (14.06)	<0.001***

[i] Values are expressed as means (*SD*). Means (*SD*) are expressed as percentages of the recorded maximum voluntary contraction of each muscle (% of maximum voluntary contraction integrated electromyography).
[ii] *, **, *** indicate significant at $P < 0.05$, 0.01, or 0.001, respectively, by ANOVA.

and feeding fish showed significant results ($P = 0.01$; Table 6). Interacting with dogs, such as hugging and combing dogs, involved higher muscle activity than other animal-mediated activities, and all eight muscles were used evenly. In animal-assisted activities, the tendency to use the right flexor carpi ulnaris muscle was remarkable. Walking dogs showed the highest use of the right flexor carpi ulnaris muscle. In addition, the right anterior deltoid and left flexor carpi ulnaris were used the most among the eight upper-extremity muscles when feeding fish, with the bowl in the left hand while standing.

Table 7 presents the analysis results for lower-extremity muscle activity during the 15 agricultural activities. Agricultural activity performed in the farm involved high lower-extremity muscle activity because the load to support the body was high owing to the use of a tool while standing and moving. Among plant-mediated activities, lower-extremity muscle activity was significant during digging, planting transplants, tying plants to stakes, and collecting natural objects ($P < 0.001$). Among plant-mediated activities, digging, planting transplants, tying plants to stakes, and collecting natural objects involved more movements than other activities, such as squatting, bending, and straightening. Among the 11 plant-mediated activities, digging exhibited the highest muscle activity. Posttest results indicated high muscle usage of the vastus lateralis and vastus medialis on the left and right sides, respectively (Table 7). Tying plants to stakes entailed high left and right vastus medialis activity. Among animal-assisted activities, walking dogs evenly used many of the eight lower-extremity muscles. Activities such as walking dogs and feeding fish showed high left and right gastrocnemius activity among the eight lower-extremity muscles.

Subjective exercise intensity of agro-healing sub-activities. The results of calculating and analyzing changes in subjective exercise intensity during the 15 detailed agro-healing activities revealed that digging (12.38 ± 3.57) and tying plants to stakes (12.52 ± 3.35) had a medium-intensity exercise perception effect. For others, raking (11.76 ± 3.22), fertilizing (9.19 ± 2.30), planting transplants (11.05 ± 2.42), watering (11.62 ± 2.87), harvesting (10.48 ± 2.74), washing (10.05 ± 2.10), cutting (8.86 ± 1.88), cooking (9.24 ± 2.04), collecting natural objects (10.14 ± 2.42), decorating natural objects (10.10 ± 2.79), holding and brushing a dog and making eye contact with it (9.62 ± 2.77), walking dogs (9.48 ± 2.54), and feeding fish (8.24 ± 1.77) had a low-intensity motor perception effect. During agro-healing activities, the 15 commonly performed movements had low-intensity (RPE 6–11, very comfortable to normal) to medium-intensity (RPE 12–15, slightly difficult to difficult) exercise perception effects (Table 8). This could be interpreted as subjective exercise intensity, which is determined by finding sensations transmitted from the body during exercise (Noble and Noble 1998).

Discussion

As a result of performing EMG while carrying out agricultural activities at the Care Farm, it was found that lower limb muscle activity was higher than upper limb muscle activity. Furthermore, plant- and animal-mediated activities involved relatively higher right muscle use than left muscle use among the upper-extremity muscles. Similar tendencies between the right and left muscles were observed for the lower-extremity muscles.

When performing the plant-mediated activities, the upper-extremity muscles showed significantly high muscle activation in tasks such as digging, raking, fertilizing, planting transplants,

Table 6. Electromyography data of upper limb muscles while performing the 15 agricultural agro-healing tasks (N = 21).

	Maximum voluntary contraction integrated electromyography [mean (*SD*)] [i]								
	Right (%)				Left (%)				
Activity	Anterior deltoid	Biceps brachialis	Brachioradialis	Flexor carpi ulnaris	Anterior deltoid	Biceps brachialis	Brachioradialis	Flexor carpi ulnaris	*P* value
Plant-mediated activity									
Digging	8.74 (5.67) bc[ii]	12.69 (8.85) b	10.83 (8.66) b	36.48 (14.73) a	4.16 (2.83) c	4.69 (3.65) c	3.74 (2.29) c	8.21 (7.09) b	<0.001***[iii]
Raking	10.96 (5.71) c	21.52 (17.55) c	17.24 (13.20) c	55.72 (33.66) a	13.29 (11.11) c	15.13 (10.02) c	13.77 (8.28) c	41.03 (22.44) b	<0.001***
Fertilizing	21.94 (8.56) b	20.33 (13.62) bcd	10.65 (8.56) de	26.61 (16.13) b	4.55 (2.75) e	21.50 (22.59) bc	11.63 (8.13) cde	37.02 (27.18) a	<0.001***
Planting transplants	17.70 (9.93) cd	17.51 (11.87) cd	12.67 (8.78) d	46.91 (21.77) a	23.06 (13.02) bc	13.85 (8.68) d	10.04 (7.85) d	29.42 (16.12) b	<0.001***
Tying plants to stakes	15.75 (6.43) bc	16.05 (10.06) bc	10.99 (9.55) c	25.38 (18.28) a	21.92 (12.01) ab	12.98 (6.67) c	9.88 (7.87) c	28.18 (16.16) a	<0.001***
Watering	19.87 (40.72) bc	20.63 (15.13) bc	18.78 (19.35) bc	38.45 (26.44) a	15.75 (13.69) bc	16.77 (13.28) bc	12.12 (7.94) c	30.82 (26.47) ab	0.004**
Harvesting	15.05 (10.64) a	14.03 (7.72) a	8.93 (6.63) bc	17.09 (10.43) a	5.14 (7.11) c	5.81 (2.64) c	5.59 (2.88) c	12.82 (9.31) a	<0.001***
Washing	16.79 (7.68) ab	15.20 (12.11) ab	10.59 (6.69) b	18.97 (1022) a	21.49 (16.40) a	14.61 (11.47) ab	11.06 (7.04) b	18.42 (11.28) a	0.014*
Cutting	19.78 (10.88) ab	17.19 (11.28) abc	8.88 (7.10) c	21.45 (12.63) ab	24.53 (23.92) a	15.22 (10.40) bc	9.70 (6.92) c	21.48 (13.30) ab	<0.001***
Cooking	16.18 (7.01) bc	16.99 (8.69) b	9.76 (7.63) de	22.97 (12.84) a	13.61 (8.62) bcde	10.70 (7.39) cde	7.85 (6.56) e	14.79 (11.17) bcd	<0.001***
Collecting natural objects	10.25 (4.05)	10.92 (6.08)	9.53 (8.42)	12.36 (7.19)	34.05 (133.12)	18.71 (20.04)	11.24 (8.65)	26.71 (22.19)	0.640
Decorating natural objects	13.12 (5.77) ab	11.68 (7.22) ab	6.10 (4.62) c	11.81 (6.76) ab	10.28 (7.78) abc	10.91 (7.20) ab	8.57 (8.01) bc	13.59 (8.19) a	0.016*
Animal-assisted activity									
Interacting with dogs	18.77 (26.79) ab	24.12 (12.48) ab	11.09 (6.91) b	30.04 (24.82) a	11.96 (8.42) b	29.64 (35.61) a	18.14 (19.84) ab	32.89 (21.50) a	0.004**
Walking the dog	5.47 (3.27) bc	6.86 (4.71) ab	4.02 (3.18) cd	8.22 (4.54) a	3.92 (3.56) cd	2.20 (1.76) de	1.34 (1.01) e	3.66 (3.41) cd	<0.001***
Feeding the fish	14.33 (9.21) a	11.61 (7.42) ab	7.86 (7.19) bc	13.76 (9.91) ab	2.78 (1.80) c	13.47 (15.97) ab	7.80 (4.57) bc	15.53 (11.02) a	<0.001***

[i] Values are expressed as means (*SD*). Means (*SD*) are expressed as percentages of the recorded maximum voluntary contraction of each muscle (% of maximum voluntary contraction integrated electromyography).
[ii] When the analysis of variance results were statistically significant, Duncan's multiple range test was conducted to determine the differences between the means of muscle activation data at $P < 0.05$.
[iii] *, **, *** indicate significant at $P < 0.05$, 0.01, or 0.001, respectively, by ANOVA.

tying plants to stakes, harvesting, cutting, and cooking, and post-test results showed that the right flexor carpi ulnaris showing the highest muscle activity ($P < 0.001$). This seems to be consistent with the findings of a previous study, in which the dominant hand used several right upper-extremity muscles during horticultural work. The flexor carpi ulnaris, which is a muscle of the arm that extends and folds, is responsible for bending and gathering the wrist and is used in most agricultural activities. As for the lower-extremity muscles, digging, planting transplants, tying plants to stakes, and collecting natural objects were significantly higher. Among the eight muscles, the vastus lateralis and vastus medialis tended to be higher than the other muscles. This prevents muscle loss and helps to stabilize the movement of the knee joint by playing a role in stabilizing the lower-extremity motion in a squatting or upright state.

During animal-assisted activities, the activities of interacting with dogs, walking dogs, and feeding fish with the upper-extremity muscles were significantly higher ($P = 0.01$). The post-test results showed that the activity of the right flexor carpi ulnaris was higher than that of the other muscles. Interaction with the dog activity activated the left arm muscles (biceps brachialis, brachioradialis, and flexor carpi ulnaris). For the lower-extremity muscles, the EMG of walking during dog activity was high, and significant results were observed during feeding fish activity ($P = 0.05$).

In this study, the right forearm muscle (flexor carpi ulnaris) was activated during agricultural work involving heavy tools. This showed the same tendency as the conclusion of a previous study that gardening activities using plants as a medium are helpful for the joints and muscles of the upper extremities and upper parts of the body, such as the hands, arms, and shoulders. Among gardening activities targeting adults, watering and cutting involve high muscle mass (Park et al. 2013b). Watering is said to be the most weight-bearing motion because of the weight of water (1.3 kg watering), and careful movements of the muscles and joints that control the force are required to aim at the target point and provide an appropriate amount of water (Park et al. 2013b).

Table 7. Electromyography data of lower limb muscles while performing the 15 agricultural agro-healing tasks (N = 21).

Activity	Maximum voluntary contraction integrated electromyography [mean (*SD*)][i] Right (%) Vastus lateralis	Right (%) Vastus medialis	Right (%) Biceps femoris	Right (%) Gastrocnemius	Left (%) Vastus lateralis	Left (%) Vastus medialis	Left (%) Biceps femoris	Left (%) Gastrocnemius	*P* value
Plant-mediated activity									
Digging	64.25 (30.31) a[ii]	77.89 (44.22) a	25.36 (18.19)	28.59 (15.99) b	72.79 (42.18) a	81.64 (46.30)	23.24 (16.87) b	28.06 (20.79) b	<0.001***
Raking	34.12 (30.14)	33.26 (25.69)	24.93 (11.57)	26.16 (15.35)	34.37 (27.62)	37.24 (32.54)	28.18 (17.97)	30.26 (12.29)	0.622[iii]
Fertilizing	14.52 (9.85)	11.70 (8.77)	17.04 (15.08)	19.85 (12.13)	17.57 (14.02)	15.00 (16.00)	18.29 (20.99)	18.94 (9.12)	0.587
Planting transplants	55.79 (30.16) a	75.19 (53.13) a	21.15 (20.12) b	28.49 (22.20) b	65.67 (38.35) a	69.18 (45.14) a	22.04 (23.35) b	25.71 (14.55)	<0.001***
Tying plants to stakes	43.61 (24.84) ab	57.08 (47.09) a	23.17 (11.98) c	30.52 (29.06) bc	46.57 (30.92) ab	51.83 (30.19) a	28.15 (17.12) bc	28.74 (13.34) bc	<0.001***
Watering	34.06 (17.82)	38.24 (25.00)	30.23 (17.05)	26.97 (17.67)	32.26 (21.27)	33.84 (23.70)	32.40 (18.02)	29.02 (11.06)	0.698
Harvesting	23.30 (18.96)	24.99 (24.62)	26.90 (16.39)	20.62 (10.46)	23.63 (19.52)	27.47 (28.76)	26.60 (22.88)	24.19 (13.00)	0.966
Washing	32.21 (20.73)	34.50 (24.97)	27.27 (19.15)	26.11 (20.32)	33.94 (26.67)	39.59 (35.48)	28.74 (21.86)	26.45 (14.74)	0.546
Cutting	3.63 (3.57)	3.71 (4.05)	4.34 (2.90)	6.32 (14.96)	3.97 (3.68)	4.10 (3.93)	5.52 (11.21)	4.29 (7.60)	0.946
Cooking	2.75 (1.61)	2.75 (2.20)	4.27 (3.12)	3.28 (2.88)	3.15 (2.04)	3.06 (2.04)	3.83 (2.93)	2.61 (1.33)	0.271
Collecting natural objects	47.46 (22.51) a	53.03 (27.55) a	25.57 (14.34) b	26.31 (21.24) b	48.41 (26.80) a	57.55 (29.42) a	25.93 (17.39) b	25.78 (15.02) b	<0.001***
Decorating natural objects	3.07 (1.87)	3.10 (2.36)	3.44 (2.59)	3.09 (3.55)	3.63 (2.22)	3.64 (2.64)	9.63 (29.95)	2.91 (2.10)	0.496
Animal-assisted activity									
Interacting with dogs	6.03 (3.18)	5.71 (3.87)	4.87 (3.32)	6.44 (5.44)	6.92 (3.91)	7.01 (4.72)	9.54 (22.55)	7.89 (5.15)	0.802
Walking the dog	25.84 (18.43)	28.21 (27.92)	20.76 (14.41)	33.26 (27.47)	28.34 (21.48)	34.61 (39.10)	18.18 (12.67)	30.87 (12.57)	0.272
Feeding the fish	8.91 (6.34) bc	6.86 (4.85) c	15.89 (12.37) abc	21.52 (23.96) a	13.16 (12.04) abc	11.35 (8.94) bc	17.17 (18.82) ab	17.58 (10.64) ab	0.011*

[i] Values are expressed as means (*SD*). Means (*SD*) are expressed as percentages of the recorded maximum voluntary contraction of each muscle (% of maximum voluntary contraction integrated electromyography).
[ii] When the analysis of variance results were statistically significant, Duncan's multiple range test was conducted to determine the differences between the means of muscle activation data at $P < 0.05$.
[iii] *, **, *** indicate significant at $P < 0.05$, 0.01, or 0.001, respectively, by ANOVA.

Kim et al. (2023) showed that the flexor carpi ulnaris was activated during agro-healing activities in adults in their 20s and 40s (31.5 ± 10.2 years), in which they grasped objects or tools with their hands. During five common gardening tasks (digging, raking, troweling, hoeing, and weeding), EMG activation was higher in the upper-extremity muscles than in the lower-extremity muscles, and among the 16 upper- and lower-extremity muscles in adults, the right brachioradialis and right flexor carpi radialis muscle activity ratios were the highest (Park et al. 2014b). Eight flower-arranging activities for physical rehabilitation have shown activation patterns in the upper-extremity muscles (Lee et al. 2012; Park et al. 2014b). Lee et al. (2012) stated that the basic movements of flower arrangement activities, such as cutting, plugging, rolling, twisting, and winding, were effective in restoring function during rehabilitation treatment by improving upper-body joint movements, muscle strengthening exercises, and hand function.

Watering while carrying a heavy bucket activated the posterior lower-extremity muscles, whereas squatting activated the anterior thigh muscles. Movements using tools while standing or activities performed while squatting resulted in gastrocnemius activation. A previous study reported that activities involving knee bending or squatting in agro-healing activities in adults in their 20s and 40s (31.5 ± 10.2 years) activated the vastus medialis and vastus lateralis, whereas weight-bearing activities, in which weight was supported while standing, activated the gastrocnemius (Kim et al. 2023). Agricultural activities, including horticultural activities, are similar to the process of rehabilitation treatment in that simple movements are repeated, and muscle activation tends to be similar to sports movements (Lee et al. 2012, 2016, 2018; Park et al. 2014b, 2015). This suggests that agricultural activities can be used for rehabilitation, physical activity, and exercise interventions. Agro-healing activities using farming work are weight-bearing exercises that use all muscles of the hands, upper extremities, and lower extremities and can be applied as treatment for patients with physical disabilities, such as the elderly and those with hemiplegia (Park et al. 2014b, 2015).

Table 8. Subjective exercise intensity by activity while performing the 15 agricultural agro-healing tasks (Rating of Perceived Exertion) (N = 21).

Variable		Category	M (*SD*)[i]	*P* value[ii]
Rating of Perceived Exertion	**Plant-mediated activity**	Digging	12.38 (3.57)	0.071
		Raking	11.76 (3.22)	
		Fertilizing	9.19 (2.30)	
		Planting transplants	11.05 (2.42)	
		Tying plants to stakes	12.52 (3.35)	
		Watering	11.62 (2.87)	
		Harvesting	10.48 (2.74)	
		Washing	10.05 (2.10)	
		Cutting	8.86 (1.88)	
		Cooking	9.24 (2.04)	
		Collecting natural objects	10.14 (2.42)	
		Decorating natural objects	10.10 (2.79)	
	Animal-assisted activity	Interacting with dogs	9.62 (2.77)	
		Walking the dog	9.48 (2.54)	
		Feeding the fish	8.24 (1.77)	

[i] M (*SD*) = Mean (*SD*).

Conclusion

In conclusion, muscle strength measurements during detailed agro-healing activities revealed that farm-type agro-healing activities improved the biomechanical muscle activity. Agro-healing activities are expected to have therapeutic value in maintaining health among individuals if they are not limited to a one-time event and are continued. In addition, this study is expected to provide basic biomechanical data when intervening in agro-healing activities for the physical health or therapeutic rehabilitation of all people. However, because the number of subjects who participated in this study was limited, there are limitations in concluding that it was a representative sample. Considering these results, additional research on various farming operations and physical function enhancement is required to develop a customized agro-healing program for actual participants.

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