



Upper Limb Muscle Activation during Vertical Farming Activities in Adults with Paraplegia and the Development of Assistive Tools

Risu Kim¹, Na-Yeon Yoo³, Mi-Sook Jeong³, Seohyun Kim², A-Young Lee⁴, and Sin-Ae Park^{5*}

¹Master Student, Department of Bio and Healing Convergence, Graduate School, Konkuk University, Seoul 05029, Republic of Korea

²Doctoral Student, Department of Bio and Healing Convergence, Graduate School, Konkuk University, Seoul 05029, Republic of Korea

³Doctoral Candidate, Department of Bio and Healing Convergence, Graduate School, Konkuk University, Seoul 05029, Republic of Korea

⁴Research Professor, Digital Humanities Agro-Healing Convergence Research Center, Konkuk University, Seoul 05029, Republic of Korea

⁵Professor, Department of Forestry and Landscape Architecture, Konkuk University, Department of Bio and Healing Convergence, Graduate School, Konkuk University, Digital Humanities Agro-Healing Convergence Research Center, Konkuk University Seoul 05029, Republic of Korea

ABSTRACT

Background and objective: Agro-healing activities often present accessibility challenges for people with physical disabilities (PWP) and vertical farms may provide a potential solution. However, there are limited empirical data regarding PWP's activities in vertical farms. This study, which comprised two studies, investigated upper limb muscle activation using electromyography (1) during vertical farming activities and (2) during these activities using universal assistive tools.

Methods: Surface electromyographic activity of the left and right anterior deltoid, biceps brachii, brachioradialis, and flexor carpi ulnaris was recorded in 22 adults with paraplegia during five vertical farming tasks: sowing seeds, transplanting seedlings, transplanting developed plants (mature seedlings), harvesting, and selecting and packaging. (2) In a separate study, the same muscles were measured in 27 adults with paraplegia while performing three tasks—soaking seeding plates, sowing, and transplanting developed plants—using both traditional methods and task-specific assistive tools.

Results: In all activities, activation of the left and right anterior deltoid was significantly higher than that of all other muscles ($p < .05$). During harvesting, activation of the left and right flexor carpi ulnaris was significantly higher compared to other activities ($p < .05$). (2) The use of assistive tools led to significantly higher activation of the right biceps brachii during soaking seeding plates, the left biceps brachii during sowing, and the right flexor carpi ulnaris during transplanting mature seedlings, compared to traditional methods ($p < .05$).

Conclusion: Vertical farming activities predominantly involve movements that require 'lifting' objects, which caused the use of the anterior deltoid muscles. The use of the developed assistive tools can promote engagement of a broader range of upper limb muscles, potentially preventing fatigue and promoting the physical and vocational rehabilitation of people with paraplegia in the context of vertical smart farming.

Keywords: agro-healing, disability, electromyography, ergonomics, rehabilitation

Introduction

According to the *Act on Welfare of Persons with Disabilities*, a person with disabilities is defined as “a person whose daily life or social activities are substantially

hampered by physical or mental disability over a long period of time.” Among this group, those who have major impairments in external physical functions or internal organs are classified as “persons with physical disabilities (hereinafter referred to as PWP).” As of 2024, 1.15 million individuals

This work was carried out with the support of the “Cooperative Research Program for Agriculture Science and Technology Development (Project No.: RS-2021-RD009877),” Rural Development Administration, Republic of Korea.

Received: September 16, 2025, **Revised:** November 24, 2025, **Accepted:** December 20, 2025

First author: Risu Kim, lococoa@konkuk.ac.kr, <https://orcid.org/0009-0006-5399-1778>

***Corresponding author:** Sin-Ae Park, sarak42@konkuk.ac.kr, <https://orcid.org/0000-0003-1367-8825>



aged 15 or older are registered as having physical disabilities, accounting for 44.7% of the total population with disabilities—the largest proportion among all disability types. Their employment rate stands at 42.3%, which is higher than the overall employment rate of persons with disabilities (33.8%). However, the number of economically inactive individuals among PWP remains substantial, at 630,000, representing the largest share across disability categories (Korea Employment Agency for Persons with Disabilities, 2024). Despite these relatively higher employment levels, PWPs continue to experience markedly lower labor-market participation compared with the general population (63.3%), underscoring the persistent need for comprehensive social interventions, including expanded vocational training opportunities and strengthened employment support services (Statistics Korea, 2024).

With the growing public interest in green environments, perceptions of agro-healing (also known as care farming, social farming, green care farming, or farming for health) have become increasingly positive (Kim et al., 2022). Numerous studies have demonstrated the psychophysiological, cognitive, and physical and rehabilitative effects benefits of agro-healing (Oh et al., 2018; Park et al., 2014a; Park et al., 2019; Lee and Park et al., 2018). However, these studies have all been conducted in outdoor agricultural settings. Agro-healing has inherent limitations in that it requires participants to travel to farms, adhere to seasonal conditions, and engage in activities that utilize both upper and lower limb muscles (Lee et al., 2018). For PWPs, particularly those with impaired lower-limb function who rely on mobility aids, access to outdoor farm settings and participation in related activities remain considerably constrained.

In addition to conventional farms, production-focused vertical farms that integrate modern engineering technologies are increasingly being utilized. A vertical farm is a fully controlled, factory-style agricultural system in which crops are cultivated within a multilayered indoor structure using ICT technologies such as smart sensors and LED artificial lighting control, thereby enabling precise regulation of environmental factors and the continuous maintenance of optimal crop-growth conditions (Lim et al., 2020). Although vertical farms were originally developed for crop production, their controlled artificial envi-

ronments also offer promising potential as agro-healing settings for PWPs. While some vertical farms have been employed as a means of job creation, research on their therapeutic effects within the context of agro-healing remains insufficient.

Vertical farms have the potential to address accessibility challenges faced by PWPs while simultaneously offering a novel environment for agro-healing. Within such settings, it is necessary to analyze the physical effects of agricultural activities. When lower limb function is limited due to physical disabilities, the roles originally performed by the agonist muscles of the lower limbs tend to be compensated for by the upper limbs through the activation of compensatory muscles (Slowik et al., 2016). Since this compensatory strategy often leads to excessive activation of the trunk and upper limb muscles, as well as alterations or reorganization of intermuscular coordination patterns, it is important to understand upper extremity muscle activation patterns during task performance in PWPs. Previous studies have also reported that changes in working conditions or tools can influence not only the magnitude of muscle activation but also its qualitative characteristics, such as activation patterns, intermuscular distribution, and co-activation strategies (Kharb et al., 2021). In particular, the use of assistive devices or adjustments to the working environment is known to induce a redistribution of physical workload, a reassignment of specific muscle roles, and overall alterations in movement strategies.

Therefore, this study was organized into two sub-studies to identify the basic patterns of upper limb muscle activation exhibited by PWPs during agricultural tasks in vertical farms, and to examine how these patterns change depending on the use of assistive tools. Study 1 characterized the overall patterns of muscle utilization for each agricultural task by measuring the upper limb muscle activation of PWPs while performing major agricultural tasks commonly undertaken in vertical farms. In Study 2, the same agricultural tasks were conducted under conditions involving the use of assistive tools, thereby enabling a comparative analysis of how such aids affected the distribution and patterns of muscle activation. Through this stepwise approach, this study aimed to elucidate both the fundamental characteristics of upper limb muscle activation among PWPs in ver-

tical farm operations and the magnitude and nature of activation-pattern changes associated with assistive tool use.

Research Methods

Study 1

Participants

A total of 22 adults with physical disabilities, aged between 20 and 65 years, who used mobility aids due to conditions such as hemiplegia or gait impairment, were recruited for this study. Recruitment notices describing the study were distributed to libraries and apartment complexes in District G, as well as to disability organizations across Seoul. To exclude potential confounding physical factors, only individuals who were right-hand dominant, had no upper limb impairments, and had no diagnosed mental disorders were included. Demographic information including age, sex, height, weight, and body mass index (measured using the ioi 353; Jawon Medical, Gyeongsan-si, South Korea) was collected. Participants received a 100,000 KRW incentive for their participation. The study was approved by the Institutional Review Board of Konkuk University (IRB No. 7001355-202209-HR-586).

Experimental Environment

This study was conducted in a greenhouse at Konkuk University within a designated experimental area measuring 220 × 160 cm. Participants were seated at a desk (180 × 90 × 90 cm) on a height-adjustable chair. For participants who had difficulty transferring to the chair, the chair was removed so that they could remain seated in their own mobility devices. The average temperature in the experimental space was 24.7 ± 3.8°C, and the relative humidity was 58.9 ± 4.5%.

Experimental Protocol

At the time of the visit, all participants were provided with a detailed explanation of the study and voluntarily signed an informed consent form prior to participation. Demographic information, including age, sex, height, and body weight, was collected through a survey. Each participant performed five agricultural tasks, with each task repeated three times. The five agricultural activities selected for this study included pre-wetting the medium (soaking seeding plates) and sowing; transplanting seedlings; transplanting developed plants (mature seedlings); harvesting; and selecting and packaging. Detailed procedures for each task are illustrated in Fig. 1. The selection of these activities was based on prior research analyzing agricultural tasks commonly performed in vertical farming environ-

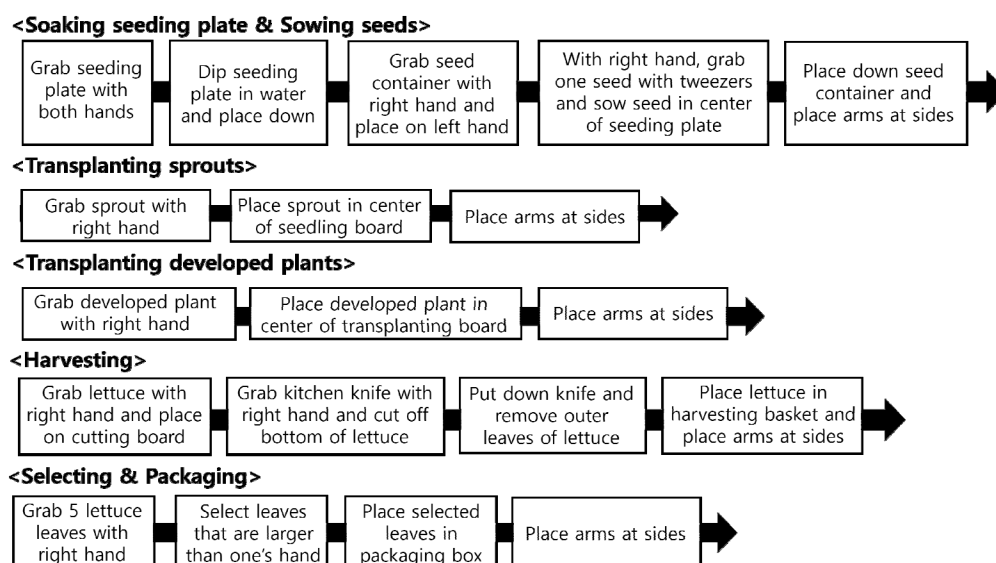


Fig. 1. Task order of agricultural activities(All activities begin and end with arms down at both sides).

ments (Yoo et al., 2023), which largely categorized the activities into six types: sowing, seedling cultivation, transplanting seedlings, transplanting developed plants, harvesting and selecting/packaging, and cleaning. Such tasks are considered to be relatively less burdensome for individuals with gait disturbances or lower-limb impairments, as vertical farming systems typically employ automated environmental controls that minimize worker movement, enabling most tasks to be performed at fixed worktables. In particular, the consistent height of cultivation shelves and worktables allows these tasks to be conducted primarily from a seated position or within a restricted range of motion, further supporting accessibility for individuals with lower-limb functional limitations (Yoo et al., 2023). Among the six classified activities, excluding seedling cultivation and cleaning, four activities were selected for the analysis. Harvesting and selecting/packaging were further divided, resulting in five target activities for which upper-limb muscle activity was assessed.

Measurement tools

A 16-channel surface electromyography (sEMG) system (Telemetry 2400 MR-XP; Noraxon, Scottsdale, AZ, USA) was used to measure muscle activity. sEMG electrodes were attached to eight upper-limb muscles: the left and right anterior deltoid, biceps brachii, brachioradialis, and flexor carpi ulnaris (Fig. 2). The muscles included in this study were selected based on a previous investigation by Park (2000), which identified the muscles frequently engaged during agricultural tasks. To standardize muscle activity, maximal voluntary contractions (MVCs) were measured for each muscle.

Data Analysis

Demographic information was organized using Excel (Microsoft Office 2016; Microsoft Corp., Redmond, WA, USA). sEMG data were processed with MyoResearch 3.16 (Noraxon, Scottsdale, AZ, USA). The recorded signals were band-pass filtered between 20 and 400 Hz, rectified, and smoothed to prepare the data for analysis. Subsequently, the maximal muscle activation derived from the MVC data was used to normalize the remaining sEMG data collected

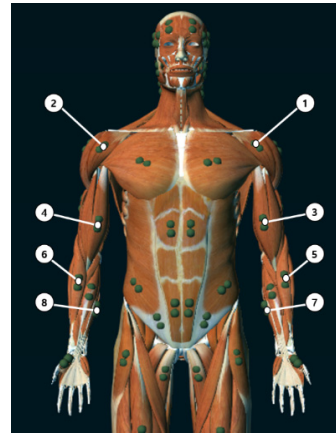


Fig. 2. Sites of sEMG electrode attachment for each muscle (1–Left anterior deltoid, 2– Right anterior deltoid, 3–Left biceps brachii, 4–Right biceps brachii, 5–Left brachioradialis, 6–Right brachioradialis, 7–Left flexor carpi ulnaris, 8–Right flexor carpi ulnaris). Electrode placement was visualized using MyoResearch 3.16.

during agricultural tasks. Statistical analyses of demographic and sEMG data were performed using SPSS 26.0 (IBM, Armonk, NY, USA). Comparisons between different agricultural tasks, as well as comparisons among muscles within each task, were conducted using the Kruskal–Wallis test (one-way ANOVA on ranks).

Study 2

Participants

An additional 30 individuals with physical disabilities, aged between 20 and 65 years, who used mobility aids due to hemiplegia or gait impairment and who did not participate in Study 1, were recruited for this study. To minimize potential physical confounders, only right-handed participants with no upper-limb dysfunction were included. Demographic information—including age, sex, height, weight, and body mass index (BMI)—was collected. Each participant received a compensation of 100,000 KRW for their involvement. The study protocol was approved by the Institutional Review Board (IRB) of Konkuk University (IRB No. 7001355-202209-HR-586).

Experiment Environment

The experiment was conducted in the same environment as in Study 1.

Experiment Protocol

sEMG was recorded while participants performed three agricultural activities—soaking seeding plates, sowing, and transplanting developed plants—under both conventional and assistive-tool conditions. Each activity was repeated three times. These three tasks were selected for Study 2 based on findings from Study 1, which identified them as activities that could be improved through the use of assistive devices.

Agricultural Activity Assistive Tools

Assistive tools were developed to enable persons with physical disabilities (PWP) to perform the three agricultural activities—soaking seeding plates, sowing, and transplanting developed plants—more conveniently and accurately. A detailed description of each tool is provided in Table 1.

Measurement tools

The same sEMG system used in Study 1 was employed, targeting the same muscles and adhering to identical meas-

urement procedures. To identify the movements exhibiting the highest muscle activation within each activity, five horticultural therapy experts and one motion-analysis specialist were consulted. Each activity was decomposed into a series of sequential movements, which were visually marked during measurement to ensure clear differentiation. Based on these procedures, the conventional soaking seeding-plate activity comprised three movements, whereas the soaking-seeding plate activity performed with an assistive tool comprised five movements. The conventional sowing activity consisted of five movements, while sowing with an assistive tool involved nine movements. The conventional transplanting activity included five movements, and the transplanting activity performed with an assistive tool consisted of eight movements (Table 2). All visual markers were recorded, and two assistants documented the timing and revised or supplemented marker positions as necessary.

Data Analysis

Data were analyzed using the same procedures described in Study 1.

Table 1. Images and descriptions of assistive tools for each agricultural activity

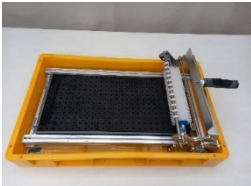
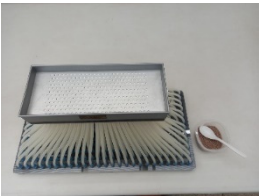
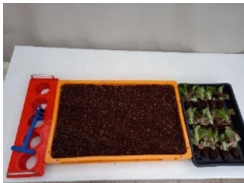
Assistive tool	Description
 <p>Soaking tool</p>	<p>A submerged metal frame attached with a roller. The user grabs the handle with their right hand and pushes the roller across the sponge plate, allowing the sponge to absorb water.</p>
 <p>Sowing tool</p>	<p>A plastic plate with several plastic tubes attached to allow simultaneous sowing of seeds. The user adds seeds to the top plate, detaches it and shakes it gently to ensure a seed fills every hole. The user reattaches the top plate and presses a button on the left to disperse the seeds to each hole.</p>
 <p>Transplanting tool</p>	<p>Consisted of a red divider and a blue tool to dig the soil, the user pushes the divider into the soil and digs the soil out of each of the five holes by twisting the blue tool. The user then removes the divider to make 5 evenly spread holes and places the crop(lettuce) plants into the holes.</p>

Table 2. Sequence of movements of each agricultural activity

Activity	Type	Description
Soaking	Traditional	<ol style="list-style-type: none"> 1. Raise both arms onto soaking plate 2. Press soaking plate into water with both hands 3. Lower arms to sides
	Assistance tool	<ol style="list-style-type: none"> 1. Support tool with left hand 2. Grab the roller handle with right hand 3. Push roller into soak plate and roll along to the left 4. Pull roller back to original position 5. Lower arms to sides
Sowing	Traditional	<ol style="list-style-type: none"> 1. Grab seed bowl with right hand 2. Place seed bowl onto left hand and pinch one seed with right hand 3. Place seed into soaking plate 4. Put seed bowl back into original place 5. Lower arms to sides
	Assistance tool	<ol style="list-style-type: none"> 1. Grab seed bowl with right hand 2. Place seed bowl onto left hand and grab spoon 3. Place spoonful of seeds into top plate 4. Return seed bowl and spoon into original place 5. Remove top plate from tool with both hands 6. Tilt top plate from left to right 7. Reattach top plate to tool 8. Press release button with left hand 9. Lower arms to sides
Transplanting	Traditional	<ol style="list-style-type: none"> 1. Grab shovel with right hand 2. Dig 5 small holes 3. Place shovel back to original place 4. Transplant 5 lettuce plants 5. Lower arms to sides
	Assistance tool	<ol style="list-style-type: none"> 1. Grab red divider with both hands 2. Place divider on soil and push into soil 3. Grab blue tool with right hand 4. Dig 5 holes with tool 5. Place blue tool into original place 6. Remove red divider back and place back in original place 7. Transplant 5 lettuce plants 8. Lower arms to sides

Results and Discussion

Demographic information

In Study 1, a total of 22 participants were recruited, comprising 16 females and 6 males. The mean age of participants was 61.32 ± 4.61 years. The average height, body weight, and body mass index (BMI) were 151.92 ± 8.11 cm, 56.60 ± 7.76 kg, and 24.48 ± 2.50 kg/m², respectively. In Study 2, 27 participants were recruited, including 21 females and 6 males. The mean age was 59.89 ± 4.28 years.

Average height, body weight, and BMI were 152.10 ± 13.97 cm, 54.78 ± 9.71 kg, and 23.84 ± 4.03 kg/m², respectively, values that fall within the normal weight range as defined by the U.S. Centers for Disease Control and Prevention (Table 3).

Electromyography results

Table 4 presents the mean muscle activation levels by agricultural task and muscle for Study 1. Across agricultural activities, the bilateral anterior deltoids exhibited sig-

Table 3. Demographic information

		Age	Height	Weight	BMI*
		Mean \pm SD**			
Study 1	Total (N = 22)	61.32 \pm 4.61	151.92 \pm 8.11	56.60 \pm 7.76	24.48 \pm 2.50
	Male (n = 6)	60.50 \pm 5.24	160.17 \pm 4.07	61.90 \pm 3.68	24.13 \pm 1.32
	Female (n = 16)	61.63 \pm 4.50	148.83 \pm 7.01	54.61 \pm 8.02	24.62 \pm 2.85
Study 2	Total (N = 27)	59.89 \pm 4.28	152.10 \pm 13.97	54.78 \pm 9.71	23.84 \pm 4.03
	Male (n = 6)	59.00 \pm 3.10	162.33 \pm 6.28	55.58 \pm 6.05	21.03 \pm 0.90
	Female (n = 21)	60.14 \pm 4.60	149.18 \pm 14.27	54.55 \pm 10.64	24.64 \pm 4.23

* Body mass index, calculated by kg/m^2 ; ** standard differential

nificantly higher activation than all other muscles ($p < 0.05$), indicating that the anterior deltoid was the most actively engaged muscle throughout all task types. When comparing muscle activation across agricultural activities, the activation levels of the left anterior deltoid and the biceps brachii differed significantly across the sequence of tasks—sowing; transplanting seedlings and transplanting developed plants; harvesting; and selecting and packaging ($p < .05$). In addition, the right flexor carpi ulnaris showed significantly greater activation during the harvesting task compared with the transplanting seedlings, transplanting developed plants, and selecting and packaging tasks ($p < .05$). This elevated activation is likely attributable to the hand motion involved in holding a knife and cutting lettuce stems during harvesting.

The upper limb muscle activation results for Study 2 are presented in Table 5. Consistent with the findings of Study 1, the bilateral anterior deltoids demonstrated significantly higher activation levels than the other muscles across all agricultural tasks, both under conventional methods and when assistive tools were used ($p < 0.01$). However, significant differences in activation levels were identified between the conventional and assistive tool methods within each activity.

During the soaking seeding-plate task, muscle activation on the left side—specifically the anterior deltoid and flexor carpi ulnaris—was significantly higher with the conventional method compared to the assistive-tool method ($p < .05$). Conversely, when using the assistive tool, activation of the right anterior deltoid, biceps brachii, and brachioradialis was significantly greater ($p < .001$). These results are further supported by the detailed movement comparisons presented

in Table 6. The use of the assistive tool required the operator to apply uniform pressure to the seeding plate by pushing a roller with the right hand, thereby engaging the right-side muscles more intensely. As a result, activation of the right anterior deltoid and flexor carpi ulnaris was significantly higher than that of other muscles during the roller-pushing motion ($p < .001$). In contrast, in the conventional method, pressure was applied directly by hand, necessitating activation of the flexor carpi ulnaris muscles in both arms to maintain the required pressing force.

When comparing traditional sowing with tool-assisted sowing, the assistive method resulted in significantly greater activation of the left biceps brachii and all right-side muscles than the conventional method ($p < .05$). As shown in the detailed movement comparison in Table 6, these muscles exhibited significantly higher activation during the detachment and reattachment of the top plate of the seeder, as well as when pressing the seeder's button ($p < .05$).

Finally, when comparing the conventional method with the tool-assisted method during the transplanting of developed plants, activation of the right flexor carpi ulnaris was significantly higher in the tool-assisted method than in the conventional method ($p < .05$). This outcome is also supported by Table 6, which shows a significant difference observed during the task of digging five holes ($p < .001$). This difference can be attributed to the design principle of the auxiliary tool, which requires rotational hand movements with applied force, in contrast to the conventional method that involves scooping soil using a traditional seedling trowel.

According to the results of Study 1, the anterior deltoid demonstrated the highest activation level across all tasks.

Table 4. Electromyography results by agricultural activity in Study 1

Agricultural activity	Right(%)(mean ± SD ³)						Left(%)(mean ± SD)						p-value
	Anterior deltoid	Biceps brachii	Brachio radialis	Flexor carpi ulnaris	Anterior deltoid	Biceps brachii	Brachio radialis	Flexor carpi ulnaris	Anterior deltoid	Biceps brachii	Brachio radialis	Flexor carpi ulnaris	
Sowing	28.96 ± 16.91 A a	16.51 ± 12.20 B a	9.97 ± 7.01 B	12.87 ± 7.45 B ab	28.71 ± 13.33 A b	12.61 ± 7.84 B a	8.69 ± 7.49 B	10.90 ± 5.17 B b	0.000***				
Trans. S. ¹	18.98 ± 15.79 A c	10.11 ± 12.30 B b	8.93 ± 7.00 B	8.91 ± 7.51 B c	20.59 ± 14.96 A bc	5.65 ± 4.12 B b	7.90 ± 6.61 B	9.29 ± 16.37 B b	0.000***				
Trans. D. ²	20.78 ± 16.47 A bc	9.46 ± 7.67 B b	10.76 ± 8.02 B	11.92 ± 10.58 B ab	19.46 ± 11.72 A c	5.65 ± 4.88 B b	8.20 ± 7.31 B	9.45 ± 10.50 B b	0.000***				
Total (N = 22)	34.71 ± 27.31 A a	13.67 ± 12.07 BC ab	13.67 ± 10.49 BC	16.28 ± 8.80 BC a	33.14 ± 14.53 A a	10.24 ± 5.76 C a	11.93 ± 8.71 C	16.80 ± 8.50 B a	0.000***				
Packaging	25.90 ± 19.38 A b	13.12 ± 10.85 B ab	10.03 ± 6.52 B	11.80 ± 8.50 B ab	28.22 ± 16.76 A b	9.18 ± 5.82 B ab	9.96 ± 6.65 B	9.87 ± 4.55 B b	0.000***				
P-value	0.003**	0.006**	0.485 ^{NS}	0.006**	0.000***	0.000***	0.203 ^{NS}	0.000***					

Kruskal-wallis test; muscle data ranked by A > B > C; activity data ranked by a > b > c; NS; non significant

*; p < .05, **; p < .01, ***; p < .001 ¹ Transplanting Seedlings; ² Transplanting Developed Plants; ³ Standard Deviation.

Table 5. Overall muscle activation during agricultural tasks in Study 2

Agricultural activity	Method	mean ± SD ³						p-value		
		Anterior deltoid(%)		Biceps brachii(%)		Brachioradialis(%)			Flexor carpi ulnaris(%)	
		Left	Right	Left	Right	Left	Right	Left	Right	
Soaking	Trad. ¹	38.50 ± 22.34 a	31.74 ± 13.13 a	9.32 ± 4.89 c	11.34 ± 10.65 c	12.78 ± 9.99 c	12.22 ± 6.82 c	24.40 ± 12.60 b	27.77 ± 23.06 b	0.000***
	A. Tool ²	27.95 ± 15.37 ab	47.87 ± 14.12 a	9.50 ± 6.01 c	22.29 ± 22.32 b	11.70 ± 5.69 c	29.56 ± 16.71 b	15.58 ± 7.51 c	19.75 ± 11.01 c	0.000***
	p-value	0.036*	0.000***	0.957 ^{NS}	0.003**	0.674 ^{NS}	0.000***	0.015*	0.612 ^{NS}	
Sowing (N = 27)	Trad.	24.20 ± 18.87 a	23.23 ± 10.06 a	8.70 ± 5.43 b	12.87 ± 11.57 b	8.05 ± 4.16 b	12.66 ± 6.68 b	5.18 ± 3.50 b	7.93 ± 4.47 b	0.000***
	A. Tool	42.34 ± 20.95 a	30.84 ± 11.62 a	16.46 ± 9.04 b	20.15 ± 18.90 b	12.75 ± 6.92 b	13.30 ± 7.67 b	10.09 ± 4.92 b	9.48 ± 5.18 b	0.000***
	p-value	0.000***	0.031*	0.000***	0.022*	0.005**	0.929 ^{NS}	0.009**	0.428 ^{NS}	
Transplanting	Trad.	36.80 ± 22.10 a	32.13 ± 12.80 a	10.64 ± 5.43 b	15.24 ± 15.32 b	13.68 ± 6.99 b	16.87 ± 8.90 b	15.79 ± 8.75 b	16.04 ± 9.16 b	0.000***
	A. Tool	43.72 ± 24.94 a	38.28 ± 12.96 a	13.03 ± 6.44 b	18.44 ± 12.81 b	14.54 ± 9.57 b	19.95 ± 8.14 b	18.39 ± 8.60 b	22.21 ± 11.38 b	0.000***
	p-value	0.247 ^{NS}	0.108 ^{NS}	0.245 ^{NS}	0.138 ^{NS}	0.700 ^{NS}	0.306 ^{NS}	0.198 ^{NS}	0.044*	

Kruskal-wallis test; ranked by a > b > c > d; NS; non significant *; p < .05, **; p < .01, ***; p < .001 ¹ Traditional; ² Assistance tool; ³ Standard deviation.

Table 6. Muscle activation during individual movements of agricultural tasks showing significant differences

Trad. ¹	mean ± SD ³				A. Tool ²	mean ± SD					
	Anterior deltoid(%)		Flexor carpi ulnaris(%)			Anterior deltoid(%)		Biceps brachii(%)		Brachioradialis(%)	
	Left	Right	Left	Right		Left	Right	Left	Right	Left	Right
Raise arms	51.50 ± 34.99 a	18.89 ± 13.04 c	11.88 ± 7.06 b	11.88 ± 7.06 b	Raise left arm	50.08 ± 42.16 b	18.89 ± 13.04 c	42.03 ± 31.37 a	42.03 ± 31.37 a	35.60 ± 21.55 a	
					Raise right arm	30.82 ± 22.03 c	11.86 ± 6.24 cd	28.98 ± 33.48 ab	28.98 ± 33.48 ab	22.63 ± 18.39 b	
Soaking					Push roller	90.95 ± 35.01 a	14.15 ± 10.01 bcd	30.78 ± 28.56 ab	30.78 ± 28.56 ab	37.35 ± 16.75 a	
					Pull roller	27.79 ± 15.47 cd	13.19 ± 8.53 bcd	19.42 ± 24.40 bc	19.42 ± 24.40 bc	27.87 ± 16.28 ab	
					Lower arms	14.18 ± 10.94 d	10.76 ± 6.74 d	11.14 ± 16.06 c	11.14 ± 16.06 c	11.06 ± 7.22 c	
					<i>p</i> -value	0.001**	0.000***	0.000***	0.000***	0.000***	
						mean ± SD					
A. Tool	Anterior deltoid(%)	Biceps brachii(%)	Flexor carpi ulnaris(%)	Brachioradialis (%)	A. Tool	Flexor carpi ulnaris(%)					
	Left	Right	Left	Right	Grab divider	Left	Right	Grab divider	Left	Right	
Total (N = 27)					Push divider	5.11 ± 5.03 d	11.00 ± 7.71 d	26.20 ± 16.24 ab	26.20 ± 16.24 ab	21.58 ± 11.95 bc	
					Grab tool	8.06 ± 5.42 d	6.06 ± 4.21 d	30.02 ± 13.94 a	30.02 ± 13.94 a	14.01 ± 7.35 cd	
					Dig holes	6.25 ± 4.53 d	6.06 ± 4.21 d	17.20 ± 9.25 cd	17.20 ± 9.25 cd	14.05 ± 11.31 cd	
					Lower tool	6.06 ± 4.21 d	6.06 ± 4.21 d	16.06 ± 18.99 cd	16.06 ± 18.99 cd		
					Remove divider	12.58 ± 6.41 bc	12.58 ± 6.41 bc				
					Planting	9.37 ± 5.49 cd	9.37 ± 5.49 cd				
					Lower arms	14.58 ± 11.08 b	14.58 ± 11.08 b				
					<i>p</i> -value	0.000***	0.000***	0.000***	0.000***	0.000***	

Kruskal-wallis test; ranked by a > b > c > d; NS; non-significant *; *p* < .05, **; *p* < .01, ***; *p* < .001¹ Traditional; ² Assistance Tool; ³ Standard Deviation.

This result is consistent with previous research showing that the anterior deltoid is the most actively engaged muscle during agricultural activities, even when performed in a seated posture (Park et al., 2014b). The muscle is well known for its substantial involvement in lifting movements that require transferring objects between different heights (Park et al., 2014b). In this study, all measured tasks entailed repetitive lifting actions, including holding the seeding plate for pre-wetting, lifting and relocating lettuce seedlings, placing harvested lettuce into a basket, and transferring lettuce leaves into a container. Thus, the significantly greater activation of the anterior deltoid compared with other muscles can be attributed to the repeated lifting demands inherent in these agricultural activities.

When comparing muscle activation among different agricultural tasks, significantly greater activation of the flexor carpi ulnaris was observed bilaterally during the harvesting activity. This muscle is known to be highly activated in tasks involving object gripping (Batzianoulis et al., 2018). The harvesting task involves holding a knife with the right hand while firmly stabilizing the lettuce plant on the cutting board with the left hand. Thus, this task likely requires greater grip strength than the other agricultural activities examined. Previous studies have reported that individuals who regularly engage in farming tasks demonstrate better hand function and cognitive performance than those who do not. These findings have been attributed to the repetitive and intensive use of hand muscles during farming, which may enhance both manual and cognitive functions (Han et al., 2018). Similarly, the repetitive hand use inherent in agricultural work may contribute to improved hand dexterity as well as cognitive ability.

In Study 1, the anterior deltoid and flexor carpi ulnaris were identified as the primary muscles engaged during agricultural activities. Particular attention should be directed to the flexor carpi ulnaris, as it is closely associated with hand function. This muscle showed the most significant activation during the harvesting task, which involves frequent contact with plants. Such plant interaction has been suggested to provide psychological benefits by promoting feelings of stability and pleasure (Rickard and White, 2021). The anterior deltoid also demonstrated relatively high activation levels, raising concerns regarding potential muscle

fatigue during repetitive and prolonged operations (Nur et al., 2015). This pattern was especially notable during the sowing activity, which requires precise and highly focused control when placing individual seeds into holes using tweezers (Szeto et al., 2009). However, it is also plausible that the elevated anterior deltoid activation observed during the sowing task was influenced by the preceding seeding-plate soaking activity rather than the sowing task itself. To address this possibility, Study 2 was conducted with the two tasks separated and analyzed independently.

In Study 2, upper-limb muscle activation was compared between conventional movements and movements assisted by three types of agricultural support tools. The results showed that both conventional and tool-assisted tasks activated the bilateral anterior deltoid muscles the most, consistent with the findings of Study 1. This pattern likely reflects the repetitive “lifting” motions required to transfer objects across different heights. These assistive tools were developed to reduce muscle fatigue during agricultural work by mitigating the repeated use of the same muscles. The experimental results indicated that the tool-assisted methods engaged a broader range of muscles compared with the conventional methods. In particular, greater activation was observed in the right biceps brachii when using the soaking tools for seeding plates, in all left-side muscles when using the sowing tools, and in the right flexor carpi ulnaris when using the transplanting tools for developed plants. Moreover, across all three agricultural tasks, the tool-assisted methods produced significantly higher activation in all upper-limb muscles than the conventional methods. Electromyography (EMG) has been widely used to determine whether rehabilitation exercises effectively activate their intended target muscles (Bolgla et al., 2005). In line with this, the findings of this study indicate that agricultural tasks performed with assistive tools in a vertical farm sufficiently engaged and activated the relevant upper-limb muscles. Therefore, further research is warranted to investigate the long-term rehabilitative effects of continuous agricultural activities using such tools.

Willingness to participate in and revisit conventional rehabilitation programs varies according to participants’ physical conditions, as well as the quality and accessibility of the training facilities, the outcomes of the training, and

its costs (Tombak et al., 2023). Agricultural activities inherently expose participants to natural elements, such as plants, which exert psychological stabilizing effects; accordingly, programs incorporating agricultural activities have been shown to enhance emotional well-being, including reductions in stress and depression (Rosa et al., 2023). Vertical farms may further increase overall satisfaction with farm-based rehabilitation programs by addressing the accessibility limitations of conventional farms while still providing exposure to natural elements through agricultural activities. Therefore, the potential benefits of vertical farm-based rehabilitation programs warrant further investigation.

Conclusion

This study evaluated upper limb muscle activation in persons with physical disabilities (PWPs) during various agricultural activities. Among the five assessed agricultural tasks, the bilateral anterior deltoid and flexor carpi ulnaris exhibited the highest levels of muscle activation. To facilitate the engagement of a broader range of upper limb muscles, assistive tools were developed for specific agricultural tasks, including soaking seeding plates, sowing, and transplanting mature seedlings. Subsequent measurements demonstrated that, during certain task-specific movements, the use of these assistive tools significantly increased activation of the bilateral biceps brachii and brachioradialis compared with conventional methods. These findings indicate that the assistive tools promoted more diverse upper limb muscle engagement during agricultural activities. Overall, this study provides a foundation for developing agro-healing-based vocational rehabilitation programs for PWPs and underscores the need for further research to expand and validate these findings.

References

- Batzianoulis, I., N. E. Krausz, A. N. Simon, L. Hargrove, and A. Billard. 2018. Decoding the grasping intention from electromyography during reaching motions. *Journal of NeuroEngineering and Rehabilitation* 15(57). <https://doi.org/10.1186/s12984-018-0396-5>
- Bolgia, L. A., and T. L. Uhl. 2005. Electromyographic Analysis of Hip Rehabilitation Exercises in a Group of Healthy Subjects. *Journal of Orthopaedic and Sports Physical Therapy* 35(8):487-494. <https://doi.org/10.2519/jospt.2005.35.8.487>
- Han, A.-R., B.-E. Ahn, and S.-A. Park. 2018. Reduced stress and improved physical functional ability in elderly with mental health problems following a horticultural therapy program. *Complementary Therapies in Medicine* 38:19-23. <https://doi.org/10.1016/j.ctim.2018.03.011>
- Jeong, J.-E., and S.-A. Park. 2021. Physiological and Psychological Effects of Visual Stimulation with Green Plant Types. *International Journal of Environmental Research and Public Health* 18(12932). <https://doi.org/10.3390/ijerph182412932>
- Kharb, S. S., Belokar, R. M., Kant, S., and Sharma, M. (2021). Biomechanical evaluation of spinal loading using farm hand tools and handle design modifications for haryana male farmers. *Journal of the Institution of Engineers (India): Series A*, 102(1):103-110. <https://doi.org/10.1007/s40030-020-00481-1>
- Kim, Y.-J., S.-O. Kim, N.-Y. Choi, S.-H. Ryu, and S.-A. Park. 2022. An Awareness and Demand Survey on Agro-Healing Among Adults with Symptoms of Stress. *Journal of People Plants Environment* 25(4):385-399. <https://doi.org/10.11628/ksppe.2022.25.4.385>
- Korea Employment Agency for Persons with Disabilities (KEAD). 2024. 2024 first half-year survey on the economic activity status of persons with disabilities. Retrieved from <https://www.kead.or.kr>
- Lee, A.-Y., Y.-A. Oh, S.-O. Kim, D.-S. Kim, and S.-A. Park. 2018. Survey on Demand and Operation Status of Care Farms in South Korea. *Journal of People Plants Environment* 21(1):1-13. <https://doi.org/10.11628/ksppe.2018.21.1.001>
- Lee, A.-Y., Park, S.-A., H.-G., Park, and K.-C., Son. 2018. 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>
- Lim, J.-H. 2020. Study on the creation of jobs in the social farming of people with developmental disabilities. *The Journal of the Korea Contents Association* 20(8):466-

479. <https://doi.org/10.5392/JKCA.2020.20.08.466>
- Merino, G., L. da Silva, D. Mattos, B. Guimaraes, and E. Merino. 2019. Ergonomic evaluation of the musculoskeletal risks in a banana harvesting activity through qualitative and quantitative measures, with emphasis on motion capture (Xsens) and EMG. *International Journal of Industrial Ergonomics* 69:80-89. <https://doi.org/10.1016/j.ergon.2018.10.004>
- Nur, N. M., S. Z. Dawal, M. Dahari, and J. Sanusi. 2015. Muscle activity, time to fatigue, and maximum task duration at different levels of production standard time. *Journal of Physical Therapy Science* 27(7):2323-2326. <https://doi.org/10.1589/jpts.27.2323>
- Oh, Y.-A., B.-E. Ahn, and S.-A. Park. 2018. Assessment of the psychopathological effects of a horticultural therapy program in patients with schizophrenia. *Complementary Therapies in Medicine* 36:54-58. <https://doi.org/10.1016/j.ctim.2017.11.019>
- Oh, Y.-A., S.-O. Kim, and S.-A. Park. 2019. Real Foliage Plats as Visual Stimuli to Improve Concentration and Attention in Elementary Students. *International Journal of Environmental Research and Public Health* 16(796). <https://doi.org/10.3390/ijerph16050796>
- Park, S.-A., A.-Y. Lee, K.-S. Lee, and K.-C. Son. 2014a. Gardening Tasks Performed by Adults are Moderate-to High-Intensity Physical Activities. *HortTechnology* 24(1):58-63. <https://doi.org/10.21273/HORTTECH.24.1.58>
- Park, S.-A., A.-Y. Lee, J.-J. Kim, K.-S. Lee, J.-M. So, and K.-C. Son. 2014b. Electromyographic Analysis of Upper and Lower Limb Muscles during Gardening Tasks. *Horticultural Science and Technology* 32(5):710-720. <http://dx.doi.org/10.7235/hort.2014.14059>
- Park, S.-A., A.-Y. Lee, H.-G. Park, and W.-L. Lee. 2019. Benefits of Gardening Activities for Cognitive Function According to Measurement of Brain Nerve Growth Factor Levels. *International Journal of Environmental Research and Public Health* 16(760). <https://doi.org/10.3390/ijerph16050760>
- Rickard, S. C. and M. P. White. 2021. Barefoot walking, nature connectedness and psychological restoration: the importance of stimulating the sense of touch for feeling closer to the natural world. *Landscape Research* 46(7): 975-991. <https://doi.org/10.1080/01426397.2021.1928034>
- Rosa, C. D., T. S. Chaves, S. Collado, L. R. Larson, K. J. Lee, and C. C. Profice. 2023. Horticultural interventions may reduce adults' depressive symptoms: A systematic review of randomized controlled trials. *Journal of Environmental Psychology* 91(102112). <https://doi.org/10.1016/j.jenvp.2023.102112>
- Rural Development Administration (RDA). 2023. Retrieved from <https://www.agrohealing.go.kr/sf/crfmIntrcn/crfm/retrieveCrfm.do>
- Slowik, J. S., McNitt-Gray, J. L., Requejo, P. S., Mulroy, S. J., and Neptune, R. R. (2016). Compensatory strategies during manual wheelchair propulsion in response to weakness in individual muscle groups: a simulation study. *Clinical Biomechanics* 33:34-41. <https://doi.org/10.1016/j.clinbiomech.2016.02.003>
- Szeto, G. P. Y., P. Ho, A. C. W. Ting, J. T. C. Poon, S. W. K. Cheng, and R. C. C. Tsang. 2009. Work-related musculoskeletal symptoms in surgeons. *Journal of Occupational Rehabilitation* 19(2):175-184. <https://doi.org/10.1007/s10926-009-9176-1>
- Tombak, Y., O. Z. Karaahmet, E. Umay, A. Tombak, and E. Gurcay. 2023. Factors influencing the willingness to participate in rehabilitation in patients with subacute stroke. *J. Clin. Neurosci.* 116:99-103. <https://doi.org/10.1016/j.jocn.2023.09.001>
- Ullah, A., A. Waris, U. Shafiq, N. B. Khan, Q. Saeed, N. Tassadaq, O. Qasim, and H. T. Ali. 2024. ExoMechHand prototype development and testing with EMG signals for hand rehabilitation. *Medical Engineering and Physics*. 124(104095). <https://doi.org/10.1016/j.medengphy.2023.104095>
- Wilson, E. O. 1984. *Biophilia*. Harvard University Press.
- Yoo, N.-Y., S.-O. Kim, and S.-A. Park. 2023. Analysis of Farm Work in a Vertical Farm. *Journal of People Plants Environment* 26(5):495-503. <https://doi.org/10.11628/ksppe.2023.26.5.495>