Muscle Activation Patterns of the Upper Limb in Agricultural Tasks: Exploring Opportunities for Vocational Rehabilitation in Vertical Farming

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Keywords. **agro-healing, biomechanics, gardening, horticulture therapy, occupational rehabilitation, smart agriculture**

Abstract. This study aimed to investigate muscle activation patterns during agricultural activities on a vertical farm. Twenty-three adults (10 males and 13 females) participated in the study. We assessed muscle activation across the following five common agricultural tasks in a vertical farming facility: seeding, temporary transplanting, transplanting, harvesting, and packing the harvest. Surface electromyography (Telemyo 2400 MR-XP; Noraxon, Scottsdale, AZ, USA) devices were placed on eight upper limb muscles: left and right anterior deltoids, left and right biceps brachii, left and right brachioradialis, and left and right flexor carpi ulnaris. All eight upper limb muscles were engaged during the tasks, and the primary muscles were the left and right anterior deltoids ($P <$ 0.001). After investigating muscle activation by task, the flexor carpi ulnaris showed significantly higher activation during the harvesting task than during the other tasks ($P < 0.05$). These findings contribute to our understanding of the biomechanical demands of agricultural activities, such as those in indoor environments in vertical farming settings. Furthermore, the results provide valuable baseline data that can be used to design vocational rehabilitation programs, particularly for individuals with disabilities. The insights obtained from this study can inform the development of more targeted training methods and educational content to optimize job rehabilitation in agricultural settings.

The Fourth Industrial Revolution (4IR), driven by the convergence of Information and Communication Technologies (ICT), such as artificial intelligence, the Internet of Things (IoT), and robotics, has been transforming industries globally (Stefanini and Vignali 2024). Agriculture has undergone considerable changes and is particularly affected by the technological advancements brought about by the 4IR. The global agricultural workforce is decreasing, comprising only 2% to 3% of the population, and aging rapidly; more than 50% of farmers in South Korea were older than age 60 years in 2018 (Statistics Korea 2024). To address these challenges, 4IR technologies have emerged as crucial solutions that enable the mechanization, automation, and modernization of agricultural practices (Sung 2018).

A type of 4R technology, ‘Smart agriculture’, has revolutionized agriculture by integrating automation, data analytics, and robotics. This transformation notably promotes productivity, operational efficiency, and sustainability, contributing to the rapid growth of the vertical farming market domestically and internationally (Walter et al. 2017). Moreover, these technologies have expanded the scope of agriculture to include urban farming, rural tourism, and agro-healing, thereby providing new opportunities for economic development and societal well-being (Sung 2018).

In addition to enhancing agricultural efficiency, the convergence of the 4IR technologies supports the shift from production-focused agriculture to a more inclusive framework that includes culture, welfare, and healing. This shift promotes “farm diversification” (Kim and Hu 2011), with agro-healing playing a key role in health promotion through agricultural and rural resources (Gim et al. 2013). The passage of South Korea’s Agro-Healing Research, Development, and Promotion Act in 2020 further advanced this field (Moon et al. 2022). Agro-healing is beneficial for physical, psychological, cognitive, and social well-being (García-Llorente et al. 2018; Park et al. 2016). Furthermore, the repetitive and task-oriented nature of agricultural work provides unique opportunities for vocational rehabilitation, particularly for individuals with disabilities (Oh 2009). The integration of vertical farming technologies creates new opportunities for inclusive employment and rehabilitation in agriculture. The controlled environment of vertical farming will be efficient and useful for people with disabilities because it will allow them to participate in agricultural work by providing a compact workspace with automated features of environmental control (Lee et al. 2022).

The advanced environment of vertical farming offers meaningful opportunities for individuals with disabilities to overcome challenges and actively participate in agricultural work (Shin 2019). Expanding employment opportunities for people with disabilities in the agricultural sector plays an important role in addressing key issues such as rural aging and labor shortages (Statistics Korea 2024). Therefore, it is essential to promote disability-inclusive employment in agriculture through tailored vocational rehabilitation and education programs.

According to the US Department of Agriculture’s Economic Research Service, as of 2019, 19% of farm operators and 9% of farmworkers in the United States were individuals with disabilities, reflecting their presence in the agricultural workforce (Miller and Aherin 2018). Each year, many individuals with disabilities seek employment in agriculture and receive support through initiatives such as the USDA’s AgrAbility program, which provides vocational training, technical assistance,

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Received for publication 8 Apr 2025. Accepted for publication 22 May 2025.

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The authors declare no conflicts of interest. The funders had no role in the design of the study; collection, analyses, or interpretation of data; writing of the manuscript; or decision to publish the results.

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This work was supported by the “Cooperative Research Program for Agriculture Science and Technology Development (Project No.:RS-2021-RD009660)” of the Rural Development Administration, Republic of Korea.

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https://doi.org/10.21273/HORTTECH05665-25

and networking opportunities. These initiatives help individuals with disabilities maintain long-term employment in agriculture and continue working in the field (Fetsch et al. 2021).

Understanding the physical demands of agricultural tasks is essential for developing effective rehabilitation programs. Muscle activation, measured through electromyography (EMG), provides valuable insights into muscle engagement during specific tasks, thereby informing task optimization and rehabilitation strategies (Kleissen et al. 1998; Kuo et al. 2011; Robertson et al. 2013). However, despite the growing interest in vertical farming as a platform for inclusive employment and vocational rehabilitation, research of muscle activation patterns in vertical farming tasks remains limited. This lack of empirical data restricts our understanding of how these tasks can be adapted for individuals with disabilities.

The framework positions this study within that context by identifying a research gap and proposing a focused examination of upper limb muscle activation during vertical farming tasks. By integrating insights from agricultural innovation (Sung 2018) and rehabilitation science (Kleissen et al. 1998; Kuo et al. 2011; Robertson et al. 2013), the framework provides a structured rationale for the study's methodological design and its relevance to inclusive, task-oriented rehabilitation approaches (Lee et al. 2018).

To fill this gap, the present study used surface electromyography (sEMG) to measure upper limb muscle activation during five common vertical farming tasks performed by healthy adults. The findings aim to provide foundational evidence to support the integration of vertical farming tasks into vocational rehabilitation and inclusive employment programs.

Understanding how these tasks engage upper limb muscles is critical to assessing their potential applicability in vocational rehabilitation settings, especially for individuals with physical disabilities. Distinct muscle activation patterns across different agricultural tasks can provide insights into the physical demands of each task and inform the development of tailored rehabilitation programs.

Therefore, this study aimed to investigate upper limb muscle activation patterns during key agricultural tasks performed in vertical farming environments. By identifying task-specific muscle engagement, the study sought to generate foundational data to support the use of vertical farming tasks in vocational rehabilitation programs.

Materials and methods

Participants. This study recruited 23 adults aged 20 to 65 years by distributing flyers in libraries and residential areas in Gwangjin-gu, an urban district in Seoul, South Korea (Table 1). The mean age of the 23 participants was 47.0 years [standard deviation (*SD*), ±14.4 years]; there were 10 male and 13 female participants. The average body mass index of the participants was 23.2 kg/m^2 (*SD*, ±4.2 kg/m^2), which was within the overweight range (Table 1). The required sample size was calculated using G*Power 3.1.9.7 (Faul et al. 2009). Based on a one-way analysis of variance (ANOVA) with a medium effect size ($f = 0.25$), a significance level of $\alpha = 0.05$, and power ($1–\beta$) = 0.95, the analysis indicated that at least 31 participants were required. However, because of practical limitations to recruiting individuals with physical disabilities—the target population of this study—a total of 23 participants were ultimately included. To minimize the influence of confounding physical factors, the study participants were restricted to individuals with a dominant right hand. Individuals with physical or mental health conditions or cardiovascular diseases that could impair their ability to perform physical tasks were excluded from the study. The participants were instructed to refrain from engaging in intense physical activity for 24 h before the study. Demographic data, including age, gender, height, weight, and body mass index (measured using IOI 353; Jawon Medical, Gyeongsan-si, South Korea), were collected. The participants received an incentive of approximately $40 (KRW 60,000) for their involvement. This study was approved by the Institutional Review Board of Konkuk University (approval number: 7001355-202209-HR-586).

Experimental procedure and condition. The experiment was conducted in an indoor workspace (180 × 160 cm) in a simulated vertical farm at Konkuk University, Seoul, Korea. The average temperature in the experimental space was 24.7 °C (*SD*, ±3.8 °C), and the average humidity was 58.9% (*SD*, ±4.5%). Participants were outfitted with sEMG (Telemyo 2400 MR-XP; Noraxon, Scottsdale, AZ, USA) electrodes attached to eight upper body muscles (Fig. 1) and performed five vertical farming tasks. Eight upper limb muscles were selected based on their frequent involvement in agricultural activities, as identified by previous studies (Lee et al. 2016; Park et al. 2013).

The selected tasks—sowing, temporary transplanting, transplanting, harvesting, and packing the harvest—were also based on a previous analysis of agricultural tasks commonly performed on vertical farms (Yoo et al. 2023) (Table 2). Specifically, tasks suitable for the vocational rehabilitation of individuals with disabilities were selected; we focused on those tasks that are easy to perform and frequently repeated in agricultural work environments (Oh 2009; Yoo et al. 2023). Lettuce (*Lactuca sativa*) was used in this study.

The experimental procedure followed the sequence outlined in Fig. 2. Before performing the vertical farming tasks, the maximum voluntary contraction (MVC) of each muscle was measured randomly. The MVC

Table 1. Characteristics of the participants.

	Mean ± *SD*		
Variable	**Male (n = 10)**	**Female (n = 13)**	**Total (N = 23)**
Age	47.7 ± 15.2	46.4 ± 14.4	47.0 ± 14.4
Height (cm)[i]	169.3 ± 7.1	159.7 ± 6.7	164.3 ± 8.3
Weight (kg)[ii]	70.2 ± 15.8	54.9 ± 7.0	62.2 ± 14.1
BMI (kg/m^2)[iii]	24.8 ± 4.1	21.7 ± 3.7	23.2 ± 4.2

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

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

[iii] Body mass index (BMI) was calculated using the following formula: weight (kg)/height (m^2). Participants were classified according to the following Asia-Pacific BMI cutoff points: underweight (<18.5 kg/m^2); normal weight (18.5–22.9 kg/m^2); overweight (23.0–24.9 kg/m^2); and obese (≥25 kg/m^2) (Kim et al. 2024).

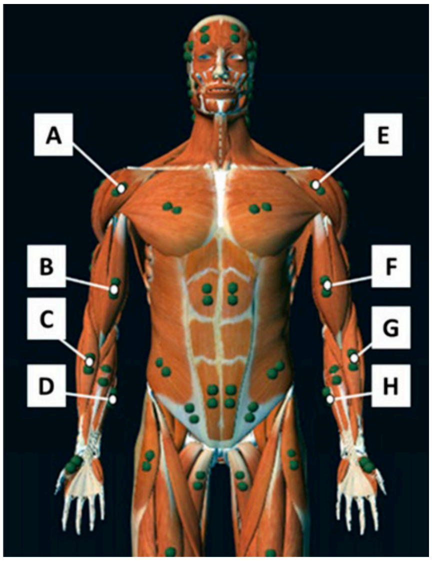

Fig. 1. Upper limb muscles measured using surface electromyography (MyoResearch XP Clinical Edition 1.07; Noraxon, Scottsdale, AZ, USA) during the indoor agriculture tasks: (A) right anterior deltoids; (B) right biceps brachii; (C) right brachioradialis; (D) right flexor carpi ulnaris; (E) left anterior deltoids; (F) left biceps brachii; (G) left brachioradialis; and (H) left flexor carpi ulnaris (Lee et al. 2016; Park et al. 2013).

of each muscle was assessed three times for 3 s, with a 1-min rest period between measurements. The postures used for MVC measurements for each muscle are listed in Table 3 (Konrad 2005). Following the MVC measurements, detailed instructions and demonstrations of indoor agricultural tasks were provided.

The participants performed all tasks while seated on a worktable (180 × 90 × 90 cm) with an adjustable-height chair. Each task began from a resting position with the arms comfortably lowered to the sides of the body. The tasks were completed three times in random order. A 30-s break was provided between each task. The study was conducted over a 2-month period from Sep 2022 to Oct 2022.

MEASUREMENTS. A portable eight-channel sEMG system (Telemyo 2400 MR-XP; Noraxon, Scottsdale, AZ, USA) was used to assess the upper limb muscle activity during the vertical farming tasks (Fig. 1). The device noninvasively measures muscle electrical activity induced by nerve stimulation using bipolar surface EMG electrodes (diameter, 22 mm; Noraxon Dual EMG Electrodes; Noraxon).

DATA ANALYSIS. The analog signals collected by the surface EMG device were digitalized in a wireless EMG analysis system, and the digital signals were analyzed using MyoResearch XP Master Edition (MyoResearch XP Clinical Edition 1.07; Noraxon). Noise in the raw EMG data (sampling rate, 1000 Hz) was eliminated using a bandpass digital filter within the cutoff range of 20 Hz (low) to 250 Hz (high), and smoothing was performed at an interval of 10 ms (Flanagan et al. 2003; Park et al. 2014). Because different detection conditions were used across the sampling of each participant's signals, the normalization of amplitude data were a prerequisite. Thus, the raw EMG data were further processed and converted to the percentage of maximum voluntary isometric contraction (%MVIC) data and the ratio of muscle activation required for the vertical farming task to reach the MVC of each muscle (Nishijima et al. 2010).

STATISTICAL ANALYSIS. The Kruskal–Wallis test was conducted to compare the EMG data across different activities and muscles using statistical analysis software (SPSS version 26; IBM, Armonk, NY, USA). Statistical significance was set at $P < 0.05$.

Table 2. Descriptions of the indoor agricultural tasks performed by the participants.

Task	Descriptions
Sowing	1) Holding the hydroponic sponge plate (65 × 38 cm, 0.2 kg) with both hands. 2) Placing the plate in a water basket (76 × 48 cm, 0.9 kg) with both hands. 3) Shaking the plate from side to side with both hands inside the soaking basket. 4) Fastening the plate on top of the basket with both hands. 5) Holding the seed container (10 × 10 cm, 0.1 kg) with the left hand. 6) Holding one seed with the right hand and sowing the seed at the center of the plate.
Temporary transplanting	1) Holding the lower left edge of the seedling tray (20 × 5 cm, 0.3 kg) with the left hand. 2) Grasping one young seedling at the center with the right hand and pulling it out. 3) Holding the left edge of the breeding tray (65 × 35 cm, 0.1 kg) with the left hand. 4) Transplanting the seedling at the center of the breeding tray with the right hand.
Transplanting	1) Holding the lower left edge of the hydroponic tray (65 × 35 cm, 0.1 kg) with the left hand. 2) Grasping one transplant at the center with the right hand and pulling it out. 3) Holding the left edge of the hydroponic tray with the left hand. 4) Transplanting the transplant at the center of the hydroponic tray with the right hand.
Harvesting	1) Holding the left edge of the hydroponic tray with the left hand. 2) Picking up the lettuce in the hydroponic tray with the right hand and placing it at the center on the cutting board. 3) Grabbing the top of the lettuce transplant with the left hand. 4) Holding the knife (25 cm, 0.3 kg) with the right hand and cutting the root part. 5) Putting down the knife. 6) Removing the outer leaves of lettuce with both hands. 7) Holding the left edge of the harvesting basket (20 × 20 cm, 0.2 kg) with the left hand. 8) Placing lettuce in the harvesting basket with the right hand.
Packing the harvest	1) Grabbing five lettuce leaves with the right hand. 2) Selecting leaves that are larger than hand size using both hands. 3) Placing selected levers in a packing box using both hands.

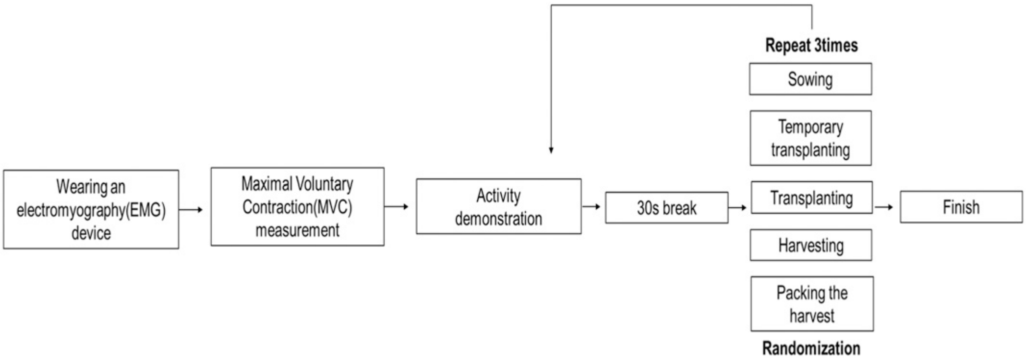

Fig. 2. The experimental protocol used for this study.

For demographic information, descriptive statistics, including means and *SD*s, were calculated using spreadsheet software (Microsoft Excel 2016; Microsoft Corp., Redmond, WA, USA).

Results and discussion

Electromyographic muscle activity during agriculture work. Five agricultural tasks engaging eight upper limb muscles were performed on a vertical farm (Table 4). Statistically significant differences in muscle activity were observed across tasks ($P < 0.001$). Notably, the anterior deltoid exhibited the highest activation on both sides during most tasks. Muscle activity was similar between the sexes, with male and female participants showing the most activation of the anterior deltoid across all five tasks (Table 4). The anterior deltoid was the most active muscle when performing the eight tasks on a vertical farm. The anterior deltoid is primarily involved in reaching out with the arm forward, abducting, or lifting to grasp objects and plays a major role in shoulder stabilization (Tokuda et al. 2016). This result indicated that the five vertical farming tasks are functional movements commonly observed in activities of daily living, such as reaching and grasping (Lee et al. 2016). These findings are similar to those of a previous study that measured indoor horticultural levels (Park et al. 2013).

The analysis of muscle activation during various vertical farming tasks revealed that, except for the flexor carpi ulnaris, no statistically significant differences were observed in the activity levels of the other muscles ($P > 0.05$) (Table 4). The flexor carpi ulnaris showed significantly greater activation during harvesting than during any other task ($P < 0.01$), followed by (in descending order) sowing, transplanting, and packing the harvest, with the lowest activation observed during temporary transplanting (Table 4). The flexor carpi ulnaris is primarily used for wrist flexion, which involves bending the wrist downward, and ulnar deviation, which involves bending the wrist toward the little finger. It is also referred to as a dynamic scaphoid stabilizer (Lung and Siwiec 2024; Salvà-Coll et al. 2011). Unlike other vertical farming tasks, this activity involved the use of a knife to cut lettuce. The dominant hand was exposed to repetitive gripping motions while holding the knife, whereas the nondominant hand showed consistent ulnar deviation and wrist flexion to hold the target harvest. In addition, lettuce, the most commonly cultivated crop on vertical farms, has soft leaves and is prone to damage, thus making delicate handling and harvesting necessary. This likely contributed to the relatively high muscle activation of the flexor carpi ulnaris compared with that of other tasks (Ma et al. 2023; Schuman 2002).

When the data were analyzed according to sex, significant differences were observed in the muscle groups that were predominantly engaged

Table 3. Maximum voluntary contraction positions of upper limb muscles based on Konrad (2005).

Muscle	Descriptions
Anterior deltoid	Participants sit on a chair with a backrest and extend both arms outward at 90°. The researcher applies pressure to their upper arms while maintaining a horizontal position. This process is repeated three times with a 5-s interval between each repetition.
Biceps brachialis	Participants sit on a chair with a backrest and rest their elbows on a support in front of them, positioning their arms at 90° to their body. Then, they bend their lower arms at 90° to their upper arms. The researcher pulls their arms outward while they resist maintaining the angle. This process is repeated three times with a 5-s interval between each repetition.
Brachioradialis	Participants sit on a chair and rest their lower arms on a support in front of them, with their palms facing upward. The researcher applies downward pressure on their lower arms while they attempt to lift them. This process is repeated three times with a 5-s interval between each repetition.
Flexor carpi ulnaris	Participants sit on a chair and rest their lower arms on a support in front of them, with their palms facing downward. The researcher applies downward pressure on their lower arms while they attempt to lift them. This process is repeated three times with a 5-s interval between each repetition.

Table 4. Muscle activation data of eight upper limb muscles during five indoor agricultural tasks using surface electromyography.

		Maximum voluntary isometric contraction (%MVIC, mean ± *SD*)								
		Right side				Left side				
Variable	Task	Anterior deltoids	Biceps brachii	Brachioradialis	Flexor carpi ulnaris	Anterior deltoids	Biceps brachii	Brachioradialis	Flexor carpi ulnaris	Significance[i]
Male	Sowing	13.5 ± 10.0 A[i]	4.5 ± 1.4 C a[ii]	5.5 ± 3.4 C	6.4 ± 3.5 BC	14.8 ± 10.5 AB	4.1 ± 1.7 C a	3.7 ± 1.8 C	4.1 ± 1.9 C b	0.000***
(n = 10)	Temporary transplanting	9.4 ± 6.0 A	2.5 ± 0.8 BC b	4.7 ± 3.6 B	3.8 ± 2.6 BC	11.0 ± 9.2 A	1.9 ± 1.1 C b	2.3 ± 1.2 BC	2.6 ± 3.1 BC b	0.000***
	Transplanting	12.0 ± 10.1 A	2.8 ± 0.8 BC b	6.5 ± 4.7 A	6.2 ± 5.2 AB	10.1 ± 8.1 A	1.7 ± 1.0 C b	2.6 ± 1.7 BC	2.9 ± 2.5 BC b	0.000***
	Harvesting	18.6 ± 13.4 A	3.5 ± 1.0 CD ab	6.6 ± 4.6 BCD	8.9 ± 6.0 B	16.9 ± 9.6 A	3.6 ± 1.5 D a	4.8 ± 2.4 BCD	6.4 ± 2.8 BC a	0.000***
	Packing the harvest	14.5 ± 10.9 A	3.5 ± 1.2 BC ab	4.9 ± 3.2 BC	5.9 ± 2.9 B	13.2 ± 7.4 A	2.6 ± 1.4 C ab	2.7 ± 1.5 BC	3.6 ± 2.5 BC b	0.000***
	Significance[ii]	0.101$^{\mathrm{NS}}$	0.009**	0.549$^{\mathrm{NS}}$	0.119$^{\mathrm{NS}}$	0.175$^{\mathrm{NS}}$	0.002**	0.068$^{\mathrm{NS}}$	0.018*	
Female	Sowing	33.8 ± 19.3 A	15.5 ± 8.2 B	14.4 ± 8.5 B	16.6 ± 6.4 B ab	31.2 ± 16.2 A	13.2 ± 5.9 B a	10.6 ± 6.1 B	12.0 ± 5.6 B b	0.000***
(n = 13)	Temporary transplanting	23.7 ± 10.7 A	9.5 ± 4.1 B	11.5 ± 8.4 B	10.8 ± 6.0 B b	24.9 ± 14.6 A	7.05 ± 2.46 B b	7.1 ± 6.0 B	7.1 ± 3.9 B c	0.000***
	Transplanting	33.5 ± 16.5 A	10.9 ± 4.8 B	13.6 ± 8.9 B	16.1 ± 8.3 B ab	32.9 ± 23.2 A	10.1 ± 4.2 B ab	11.1 ± 9.3 B	13.2 ± 6.5 B ab	0.000***
	Harvesting	47.2 ± 24.6 A	14.3 ± 5.3 B	20.4 ± 11.0 B	24.2 ± 10.5 B a	42.2 ± 20.0 A	13.2 ± 5.8 B a	16.6 ± 11.6 B	19.7 ± 10.0 B a	0.000***
	Packing the harvest	33.2 ± 14.9 A	12.6 ± 6.1 B	13.2 ± 8.6 B	13.6 ± 5.8 B b	32.7 ± 11.2 A	11.3 ± 4.7 B ab	9.6 ± 7.6 B	12.3 ± 8.3 B b	0.000***
	Significance	0.103$^{\mathrm{NS}}$	0.058$^{\mathrm{NS}}$	0.112$^{\mathrm{NS}}$	0.004**	0.130$^{\mathrm{NS}}$	0.010*	0.237$^{\mathrm{NS}}$	0.001**	
Total	Sowing	25.0 ± 18.7 A	10.7 ± 8.27 B	10.5 ± 8.0 B	12.2 ± 7.4 B ab	24.0 ± 16.1 A	9.3 ± 6.5 B	7.6 ± 5.8 B	8.6 ± 5.9 B ab	0.000***
(N = 23)	Temporary transplanting	17.5 ± 11.4 A	6.5 ± 4.7 B	8.5 ± 7.5 B	7.7 ± 5.9 B b	18.8 ± 14.2 A	4.8 ± 3.3 B	5.0 ± 5.0 B	5.1 ± 4.2 B b	0.000***
	Transplanting	24.1 ± 17.5 A	7.4 ± 5.5 B	10.5 ± 8.1 B	11.8 ± 8.6 B ab	23.0 ± 21.3 A	6.4 ± 5.3 B	7.4 ± 8.2 B	8.7 ± 7.3 B ab	0.000***
	Harvesting	34.7 ± 24.8 A	9.6 ± 6.8 BC	14.4 ± 11.1 BC	17.5 ± 11.6 B a	31.2 ± 20.5 A	9.0 ± 6.6 C	11.5 ± 10.6 BC	13.9 ± 10.1 BC a	0.000***
	Packing the harvest	25.1 ± 16.1 A	8.6 ± 6.5 B	9.6 ± 7.9 B	10.3 ± 6.1 B ab	24.2 ± 13.7 A	7.5 ± 5.7 B	6.6 ± 6.7 B	8.5 ± 7.7 B ab	0.000***
	Significance	0.110$^{\mathrm{NS}}$	0.158$^{\mathrm{NS}}$	0.221$^{\mathrm{NS}}$	0.014*	0.172$^{\mathrm{NS}}$	0.066$^{\mathrm{NS}}$	0.144$^{\mathrm{NS}}$	0.005**	

[i] Analysis of muscles was performed using the Kruskal–Wallis test. The derived rankings are written in uppercase.

[ii] An analysis of indoor agricultural tasks activities was performed using the Kruskal–Wallis test. The derived rankings are written in lowercase.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

during different tasks (Table 4). In males, the left and right biceps brachii showed significantly higher activity during the sowing task, whereas the right biceps brachii and left flexor carpi ulnaris were the most activated during the harvesting task ($P < 0.05$). In females, the left biceps brachii was predominantly activated during the sowing task, whereas both the left and right flexor carpi ulnaris, along with the left biceps brachii, were more active during the harvesting task ($P < 0.05$). The observed differences in muscle activation characteristics between the male and female participants during the agricultural tasks in this study are likely attributable to variations in motor control aspects, such as muscle coordination and movement strategies during upper limb tasks (Srinivasan et al. 2016). These gender-based differences in muscle activation are consistent with those reported by previous studies that demonstrated physiological differences between males and females when performing the same tasks under the same conditions (Cote 2012; Lewis and Mathiassen 2013).

Compared with previous studies that measured upper limb muscle activation during outdoor agricultural activities such as digging and raking, which showed maximum activations of 61.5%MVIC (*SD*, ±74.9%MVIC) in the upper limb (Park et al. 2014), the maximum muscle activation for the agricultural tasks in this study was 34.8%MVIC (*SD*, ±24.8%MVIC) in the upper limb muscles. These results suggest that the upper limb muscle activation required for agricultural activities is approximately half that required for outdoor agricultural tasks (Park et al. 2014). Therefore, compared with traditional agricultural work outdoors, modern agricultural tasks, such as those performed on vertical farms, can be considered less physically demanding and less likely to induce considerable physical fatigue or strain.

Smart agriculture provides substantial potential for vocational rehabilitation training for individuals with disabilities. This type of work involves performing simple, repetitive tasks while seated on a workbench. This primary work environment requires minimal physical exertion (Oh 2009; Park 2022). A farming environment can be automatically controlled using ICT, thus making it accessible and manageable. A previous pilot study that implemented a hydroponic cultivation and succulent plant propagation program on a vertical farm for the vocational training of individuals with intellectual disabilities reported positive rehabilitation effects, including improvements in hand function, work adjustment skills, and job preferences (Joo et al. 2012; Joy et al. 2020).

In conclusion, this study provided foundational data about muscle activation patterns during agricultural activities on vertical farms. Considering the global trend of expanding agriculture to comprise welfare, healing, and therapeutic applications through the FIR, the results of this study are notable for using agricultural tasks as tools for agro-healing and vocational rehabilitation of individuals with disabilities. However, to further refine our understanding, future research could explore muscle activation patterns in individuals with different types of disabilities during agricultural work on vertical farms. Additionally, while the vertical farming tasks were conducted under controlled experimental conditions, real-world work environments may introduce variable factors that could influence task performance. As such, future studies could focus on examining these patterns in more dynamic, real-world settings to better reflect the complexities of agricultural work.

Furthermore, it would be beneficial to develop and implement customized vocational training programs that leverage agriculture-based vertical farming activities. Such programs have the potential to improve the physical, psychological, and social well-being of individuals with disabilities, and their effectiveness should be thoroughly evaluated in future research.

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