Electromyographic Analysis of Upper Limb and Hand Muscles during Horticultural Activity Motions

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Additional index words. muscle activation, physical rehabilitation, gardening, horticultural therapy, human issues in horticulture

Summary. This study used electromyographic analysis to investigate specific upper limb and hand muscle activation during 15 common horticultural activities. A total of 30 Korean adults between the ages of 20 and 30 years, with an average age of 24.8 years, were recruited from Konkuk University, Seoul, South Korea. Electromyographic measurements were made using a portable four-channel electromyograph. Bipolar surface electromyography (EMG) electrodes were attached to six upper limb muscles (i.e., upper trapezius, triceps—long head, biceps brachialis, flexor carpi ulnaris, flexor carpi radialis, and brachioradialis) and two hand muscles (i.e., thenar eminence and hypothenar eminence) on the dominant hand. These eight muscles that were selected play a major role in the operation of upper limbs and hand muscles for upper body low-impact activities. Each participant did the 15 horticultural activities on one occasion with two separate sessions. Each activity was performed for 60 seconds followed by a 15-second rest period sitting at a table on a height-adjusted chair between each activity. All eight muscles measured were used together during most of 15 horticultural activities. Upper trapezius, thenar eminence, and hypothenar eminence had higher muscle activity than the other muscles. Triceps—long head displayed very low EMG values compared with the other muscles. The EMG data will facilitate developing scientific and research-based gardening intervention and/or horticultural therapy programs for improving physical health and physical rehabilitation.

Participation in horticultural activities has significant human health benefits. For example, lower cholesterol and blood pressure (Armstrong, 2000), better balance and gait speed (Chen and Janke, 2012), better hand functional ability (Park et al., 2009), fewer chronic conditions and functional limitations (Chen and Janke, 2012), improved overall physical health (Park et al., 2009), lower stress (Hawkins et al., 2011; Van Den Berg and Custers, 2011), better life satisfaction (Sommerfeld et al., 2010), and improved psychological well-being and social integration (Waliczek et al., 2005; Walsh et al., 2001) have each been attributed to horticultural activities.

Various horticultural activities involve physical exercise. Most gardening activities were determined as low to moderate physical activities in previous studies (Ainsworth et al., 2011; Gunn et al., 2005; Park et al., 2008a, 2008b, 2011, 2012). Ainsworth et al. (2011) reported 53 common gardening tasks as low to moderate in physical intensity in adults aged 25 to 65 years based on published data or estimates by experts on physical activity. Park et al. (2008a, 2011) reported that gardening activities using both the upper and the lower body (e.g., digging, weeding) were moderate in intensity while activities that mainly used the upper body (e.g., mixing soil, planting seedlings) involved low-intensity physical activity in adults over 65 years old. Horticultural activities such as propagation (cutting herbs) or planting transplants that used mainly the upper body while standing involved low-intensity physical activity, while making a vegetable garden combined both upper and lower body muscles at a moderate intensity (Park et al., 2012).

Moreover, weight-bearing motions are body movements that work against gravity. Weight-bearing exercise improves muscle strength and physical functional ability (Olivetti et al., 2007). Exterior stress such as high-intensity exercises that require mechanical load stimulates new bone formation (Turner and Robling, 2003). Weight-bearing gardening motions (e.g., digging, weeding) can improve muscle strength and bone mineral density (Restuccio, 1992; Turner et al., 2002).

Electromyography detects the electrical signal produced by muscle cells when these cells are electrically or neurologically activated. EMG has been used to investigate muscular activity, and the signals can be analyzed to detect medical abnormalities and activation level, or to analyze the biomechanics of human or animal movement (Bolgla and Uhl, 2007; De Luca, 1997). In a previous study, muscle activation for the motions of flower arrangements such as cutting, bending, and winding were analyzed by EMG (Lee et al., 2012). Although horticultural activities have been used for improving physical rehabilitation of individuals with disabilities (Jung, 2005; Kim, 2001), there is little EMG information on various horticultural activities that could potentially be used to maximize the positive effects of therapy. As a consequence, this study investigated specific muscles that play a major role in the operation of upper limbs and hand muscles for upper body low-impact activities and their activation using EMG measurements during 15 common horticultural activities in adults.

Materials and methods

Participants. A total of 30 adults between the ages of 20 and 30 years (20 males, 10 females) from Konkuk University, Seoul, South Korea, volunteered to participate in

This article was supported by Konkuk University in 2012.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

the study. Criteria for participation were age and the absence of exercise for the muscles of the upper limbs 24 h before testing. The participants were provided descriptive information for all procedures to be used in the study. Demographic and health information (e.g., age, gender, dominant hand, experiences of neurologic diagnosis, pain in upper limbs or hands during the past six months) were collected. The average age of the participants was (±SD) 24.8 ± 2.8 years. All of the participants were right-handed, and no one had experienced any neurological problems or pain in the upper limbs or hands during the past six months. The mean height and body weight of the participants were 171.1 ± 8.6 cm measured by anthropometer (model ok7979; Samhwa, Seoul, South Korea) and 70.3 ± 14.9 kg measured by body weight analyzer (model B5010; Shenzhen Simple Electronics, Shenzhen, China), respectively. A gift card was provided as an incentive for each participant at the completion of the test.

HORTICULTURAL ACTIVITIES. Fifteen common horticultural activities using primarily upper limbs and hand muscles were performed by the 30 participants in a glass greenhouse on the Konkuk University campus. The participants did each horticultural activity for 60 s (see Table 1 for detail descriptions) followed by a 15-s rest between each activity while sitting at a table on a height-adjustable chair to reduce noise for EMG value by unstable shoulder position. The participants were required to repeat the same motions for the each activity during the testing time. In our preliminary test, a 60-s activity time and a 15-s resting period were found to be sufficient for the electromyographic analysis because EMG values of one

Table 1. Descriptions of 15 horticultural activities for electromyographic analysis of upper limb and hand muscles during horticultural activity motions.

No.	Horticultural activity	Description[z]
1	Mixing growing medium 1—turning	Turning growing medium (7 peatmoss:3 perlite) in a bucket [14 L (3.7 gal)] using both hands. Water was added until damp in the growing medium.
2	Mixing growing medium 2—rubbing	Rubbing growing medium (7 peatmoss:3 perlite) in a bucket (14 L) using both hands to break up large chunks of peatmoss.
3	Filling a container with growing medium with hand trowel	Filling a container [diameter 15 cm (5.9 inches), height 7 cm (2.8 inches)] with growing medium (7 peatmoss:3 perlite) using hand trowel [0.1 kg (0.2 lb)] using the dominant hand.
4	Filling a container with growing medium by hands	Filling a container (diameter 15 cm, height 7 cm) with growing medium (7 peatmoss: 3 perlite) using the dominant hand. Grasping a handful of soil and then putting it in the bucket.
5	Filling a tray with growing medium	Filling a 50-plug with growing medium (7 peatmoss:3 perlite) using the dominant hand. Grasping a handful of growing medium and filling the holes.
6	Planting plants	Planting plants in a 10-cm (3.9 inches) plastic pot using both hands. Filling the pot with growing medium (7 peatmoss:3 perlite), planting the plant in the middle of the pot, and then covering the roots with growing medium.
7	Making moss balls	Grasping a handful of wet moss and squeezing it into a ball. Wet moss previously prepared in a bucket (diameter 15 cm, height 7 cm).
8	Removing leaves from plants	Picking rosemary (*Rosmarinus officinalis*) leaves using the dominant hand with the other hand holding the stems. This activity is similar to harvesting vegetables such as peppers (*Capsicum annuum*) and cherry tomatoes (*Solanum lycopersicum*), or deadheading of flowers.
9	Sticking cuttings	Sticking rosemary cuttings in cells of a 50-hole tray filled with growing medium (7 peatmoss:3 perlite) by the dominant hand. Grasping a stem from a bucket and then placing the stem in the middle of a hole on the tray.
10	Sowing seeds	Sowing bean seeds in a 50-hole tray filled with growing medium (7 peatmoss:3 perlite) by the dominant hand. Grasping a seed from a bucket and then planting the seed in the middle of a hole in the tray.
11	Dividing plants	Dividing the stems and roots of syngonium plants (*Syngonium podophyllum*) in 10-cm plastic pots using both hands. Removing the plant from the pot, removing some growing medium around the roots, and dividing the stems and roots.
12	Cutting stems	Cutting rosemary stems with scissors (0.1 kg) using the dominant hand with the other hand holding the stem.
13	Watering using a watering can	Watering syngonium plants planted in a 10-cm plastic pot by watering can [1.3 kg (2.9 lb)]. Holding the watering can by the dominant hand and then watering the plants.
14	Watering with a spray bottle	Watering syngonium plants planted in a 10-cm plastic pot using a spray bottle [0.5 kg (1.1 lb)]. Holding the spray bottle with the dominant hand and then spraying the plants.
15	Writing name tags	Writing names on a paper using the dominant hand to hold the pen.

[z]All participants sat on a height-adjusted chair and all horticultural activity materials were previously prepared on a table. The participants were required to repeat the same motions for the each activity for 60 s and then had a 15-s rest while sitting on the chair between each activity.

activity for 60 s maintained a certain range and a 15-s resting period allowed the values to revert back to an initial value. The activities were randomized for each participant. Participants wore a short-sleeve shirt to allow attachment of the EMG patches on their upper limb and gloves to protect the patches on the hands. The average temperature in the glasshouse was (±SD) 25.2 ± 4.9 °C and the relative humidity was 38.0% ± 26.2% (Acuba CS-201 digital hygro-thermometer; Chosun, Guangdong, China). These environmental conditions were appropriate for the research conducted in this study.

Measurements. A portable four-channel EMG instrument (Myotrace 400; Noraxon, Scottsdale, AZ) was used. Bipolar surface EMG electrodes [silver/silver chloride (Ag/AgCl), 8-mm radius] were attached to six upper limb muscles (i.e., upper trapezius, triceps—long head, biceps brachialis, flexor carpi ulnaris, flexor carpi radialis, and brachioradialis) and two hand muscles (i.e., thenar eminence and hypothenar eminence) on the dominant hand (Fig. 1). These eight muscles, which were selected by the experts in laboratory of biomechanics, Department of Industrial Engineering, Hongik University, play a major role in the operation of upper limbs and hand muscles for upper body low-impact activities. Disposable, self-adhesive pregelled Ag/AgCl dual electrodes were positioned parallel to and over the center of each muscle (Fujii and Moritani, 2012; Hawkes et al., 2011). The interelectrode distance (center to center) was 1 cm (Hong and Kim, 2009). To reduce interelectrode resistance, the surface of the skin was treated with alcohol before the electrodes were attached (Fujii and Moritani, 2012; Hawkes et al., 2011). Bipolar disposable hook wire electrodes were used for the intramuscular recording of activity. Thin elastic nylon bandages were then used to firmly hold the lead lines to the body to prevent artifacts that might be caused by displacement of the electrodes.

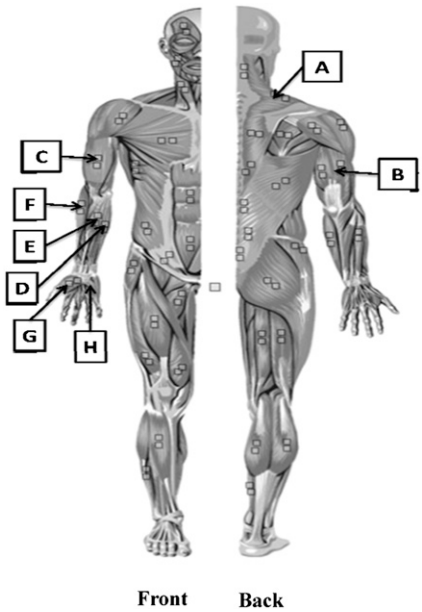

Fig. 1. Names of upper limb and hand muscles tested for electromyographic analysis during 15 horticultural activity motions: (A) upper trapezius, (B) triceps—long head, (C) biceps brachialis, (D) flexor carpi ulnaris, (E) flexor carpi radialis, (F) brachioradialis, (G) thenar eminence, (H) hypothenar eminence (MyoResearch XP Clinical Edition 1.07 software; Noraxon, Scottsdale, AZ).

The participants completed the 15 activities on one occasion with two separate sessions since only four muscle positions could be tested at the same time. The triceps—long head, flexor carpi radialis, thenar eminence, and hypothenar eminence were randomly measured during the first session, and the upper trapezius, biceps brachialis, flexor carpi ulnaris, and brachioradialis were tested in the second session after a 10-min rest. Before starting the first activity in each session, the participants sat on a chair with their hands on their knees for 30 s to obtain a resting EMG measurement as an EMG baseline. A 30-s resting time was found to be sufficient for the electromyographic analysis in our preliminary testing.

Data analysis. Descriptive information was handled using Excel (Office 2007; Microsoft Corp., Redmond, WA). MyoResearch XP Clinical Edition 1.07 software (Noraxon) was used for analyzing EMG data for the horticultural activities. The sampling frequency was 1000 Hz and the data for the first 3 s was deleted to compensate for the time required to start an activity. Duncan's multiple range tests at $P < 0.05$ were used to compare means using SAS (version 9.3 for Windows; SAS Institute, Cary, NC).

Results and discussion

The participants used all eight muscles during the 15 horticultural activities although the degrees of usage varied among muscles (Table 2). Mixing soil involved two motions: turning soil in the bucket and rubbing soil by hand to break up clods (Table 1). The upper trapezius and biceps brachialis were mainly used for turning and rubbing soil by hand, whereas breaking up clods used more upper limbs and hand muscles than turning soil (Table 2).

Filling a bucket with growing medium and transplanting plants primarily used the upper trapezius, thenar eminence, and hypothenar eminence (Table 2). To fill a container or a tray with growing medium, the participants picked up the growing medium by hand or using a hand trowel and then transferred it into a container or tray from the bucket (Table 1). The hypothenar eminence and thenar eminence were significantly used during the gripping motions required for picking up the growing medium and the upper trapezius for transferring growing medium from the bucket to the tray. The muscles such as biceps brachialis and brachioradialis were significantly used during the task, filling a container with growing medium by hand trowel because of holding a weighty tool such as hand trowel (Table 2).

Planting involved two steps: partially filling the pot with growing medium and then adding additional growing medium around the plant, each of which was done by hand (Table 1). In this activity, the participants used hypothenar eminence and thenar eminence to pick up growing medium for filling the pot by dominant hand. The upper trapezius was also used for transferring the growing medium from the bucket to the pot, which was similar trend with previous activities, filling a container or a tray with growing medium (Table 2).

Making moss balls used the upper trapezius, biceps brachialis, flexor carpi ulnaris, brachioradialis, thenar eminence, and hypothenar eminence (Table 2). Making moss balls required gripping and squeezing, the latter of which required more strength than gripping motion.

Removing leaves from plants, sticking cuttings, sowing seed in a tray, and dividing plants mainly required gripping, using the thumb and forefinger. Therefore, the thenar eminence and hypothenar eminence displayed

Table 2. Data for electromyography (EMG) of upper limb and hand muscles during 15 horticultural activity motions.

		Mean EMG (μV)								
		Upper limb muscles						Hand muscles		
						Forearm				
No.	Horticultural activity	Upper trapezius	Triceps—long head	Biceps brachialis	Flexor carpi ulnaris	Flexor carpi radialis	Brachioradialis	Thenar eminence	Hypothenar eminence	*P*
1	Mixing growing medium 1—turning	244.1a[z]	37.4 f	166.1 b	75.7 de	62.0 ef	87.8 de	128.2 c	95.4 d	***
2	Mixing growing medium 2—rubbing	176.3 b	58.0 d	213.3 a	95.6 c	119.6 c	110.0 c	105.6 c	111.6 c	***
3	Filling a container with growing medium by hand trowel	220.3 a	31.2 c	105.6 b	61.7 c	63.9 c	134.9 b	100.0 b	121.9 b	***
4	Filling a container with growing medium by hands	221.1 a	36.6 e	100.2 cd	77.1 d	67.7 de	117.2 c	172.6 b	186.2 ab	***
5	Filling a tray with growing medium	212.2 a	41.7 f	96.7 cde	67.2 ef	78.0 de	103.8 cd	127.6 bc	143.7 b	***
6	Planting plant	178.5 a	27.6 e	93.8 cd	69.2 de	69.8 de	106.6 bcd	135.5 bc	138.8 ab	***
7	Making moss balls	217.8 a	54.2 d	154.4 bc	146.3 bc	117.1 c	145.0 bc	159.2 bc	178.4 ab	***
8	Removing leaves from plants	145.4 a	22.1 d	68.7 bc	42.8 cd	48.0 cd	91.8 b	96.1 b	160.8 a	***
9	Sticking cuttings	146.0 a	20.7 d	68.6 c	50.5 cd	52.2 cd	59.5 bc	119.3 ab	157.1 a	***
10	Sowing seeds on a tray	161.6 a	29.9 b	71.0 b	63.8 b	63.5 b	89.7 ab	173.1 a	160.5 a	***
11	Dividing plants	133.3 b	27.6 d	105.7 bc	73.9 c	72.0 c	116.4 b	136.5 b	184.5 a	***
12	Cutting stems	218.0 a	21.4 d	78.7 bc	57.2 c	55.5 c	105.0 b	77.3 bc	64.5 c	***
13	Watering by watering can	249.9 a	29.3 e	142.2 c	56.1 de	56.9 de	199.8 b	77.7 d	93.5 d	***
14	Watering with a spray bottle	207.9 a	26.9 c	116.7 b	132.4 b	100.5 b	212.7 a	120.1 b	90.6 b	***
15	Writing name tag	47.7 cd	32.3 d	27.6 d	66.1 c	60.3 c	88.0 b	92.0 b	117.2 a	***
	Resting[y]	8.6	7.3	8.5	4.5	6	7.3	7.1	5.3	NS

[z]Means of EMG data for upper limb and hand muscles during 15 horticultural activity motions sharing a common letter are not significantly different by Duncan's multiple range tests at $P < 0.05$.
[y]Participants sat on a chair and put their hands on their knees for 30 s for measuring the EMG data of resting position.
***Significant at $P < 0.001$; NS = no significant difference at $P < 0.05$.

higher EMG values than the upper trapezius (Table 2).

The participants primarily used their upper trapezius and brachioradialis when watering with a watering can and when cutting stems (Table 2). Both activities consisted of weight-bearing motions (e.g., holding and squeezing a tool). Watering was the highest weight-bearing activity among all of the activities because of the weight when full (1.3 kg) (Table 1). Spray watering also involves a weight-bearing action where 0.5 kg of spray was lifted and repeatedly squeezed. The upper trapezius, biceps brachialis, flexor carpi ulnaris, flexor carpi radialis, brachioradialis, thenar eminence, and hypothenar eminence were significantly used (Table 2).

Hand muscles (e.g., thenar eminence and hypothenar eminence along with the brachioradialis of the forearm) were used when writing name tags (Table 2). The participants gripped a pen and then wrote the names repeatedly, in particular using the thenar eminence.

Given all the results, for almost all activities the primary muscle used was the upper trapezius, an upper limb muscle. The upper trapezius is usually used in most of the activities using neck and arms and appears to be more activated during the activities in sitting than in standing position (Astrand et al., 2003). Six activities—filling a container, planting, making moss balls, removing leaves, sticking cuttings, and sowing seeds—also demonstrated primary use of a hand muscle, the hypothenar eminence. Gardeners had previously been shown to have higher hand function ability (hand strength and pinch force) than non-gardeners (Park et al., 2009; Reynolds, 1999). In an observational study, gripping was required in more than 80% of the gardening tasks tested (e.g., weeding; cleaning tools, hands, or produce; carrying tools; harvesting; watering; cutting flowers or stems; pruning; mowing; deadheading; digging; mulching; and planting plants) (Park and Shoemaker, 2009). The horticultural tasks included gripping or squeezing and would involve using the thenar eminence and hypothenar eminence. Relf (1973) also suggested that gardening activities provide an opportunity to practice grasp and release and flexion of thumb and forefinger. Sowing seeds and watering

with a spray bottle demonstrated the widest dominant muscle use, with the upper trapezius, brachioradialis, thenar eminence, and hypothenar eminence all primarily involved. This implies that these horticultural activities would be useful for subjects who need to improve the upper limb and hand function. Involvement of the forearm, through the use of the brachioradialis, was demonstrated when using a spray bottle, but the forearm muscles were not dominant for the other activities. This finding that a horticultural activity can specifically improve a certain muscle part of human body is fundamental and useful information and can be applied to developing horticultural therapy program. Consistently low EMG values in most of the horticultural activities were observed in the triceps—long head. This muscle is primarily used in extension motion such as pushing with arms or extending the lower arm, whereas the activities such as lifting objects requires biceps to be active as a flexor and the role of triceps is mostly antagonistic to biceps (Astrand et al., 2003) during the horticultural activities used in this study. Thus, the EMG values of the triceps were generally low during the horticultural activities used in this study. Regarding gender, muscle strength of female is generally known as ≈70% of the male muscle strength (Astrand et al., 2003). However, there was no significant difference for EMG data of the upper limb and hand muscles tested except upper trapezius for the horticultural activities in this study (data not shown). Lee et al. (2012) conducted an EMG analysis for the motions of flower arrangement such as cutting, bending, fixing, and winding to develop a horticultural therapy program for rehabilitation by using flower arrangement movements. Various horticultural activities have been also applied as a treatment in horticultural therapy for physical rehabilitation (Jung, 2005; Kim, 2001), but there is not enough supportive data for the mechanisms on how the various horticultural activities affect the human physical body. The electromyographic analysis of this study provides fundamental and scientific information in the aspect of muscles.

In conclusion, six muscles (i.e., upper trapezius, triceps—long head, biceps brachialis, flexor carpi ulnaris, flexor carpi radialis, and brachioradialis) in the upper limbs and two (i.e., thenar eminence and hypothenar eminence) in the hand were varied when doing a cross section of horticultural activities. Overall, the upper trapezius, thenar eminence, and hypothenar eminence in the hand displayed higher muscle activity than the other muscles measured. Meanwhile, the triceps—long head displayed very low EMG values compared with the other muscles suggesting little link between the activation of triceps, an upper limb muscle, and common indoor horticultural activities. The thenar eminence and hypothenar eminence were the primary muscles used for gripping, which is one of frequented motions used for the horticultural activities. The upper trapezius was primarily used for activities such as transferring, lifting, and weight-bearing motions where holding or squeezing was required. To develop scientifically based gardening intervention or horticultural therapy programs for improving physical health or for physical rehabilitation, EMG data for horticultural activities are invaluable.

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