J. Phys. Ther. Sci. 28: 881–885, 2016

The Journal of Physical Therapy Science

Original Article

Muscle activity and mood state during simulated plant factory work in individuals with cervical spinal cord injury

Satoshi Okahara[1, 2)*], Masataka Kataoka[2)], Kuniharu Okuda[2)], Masato Shima[2)], Keiko Miyagaki[3)], Hitoshi Ohara[4)]

[1)] *Department of Rehabilitation, Osaka General Medical Center: 56-1-3 Mandai-Higashi, Sumiyoshi-ku, Osaka 558-8558, Japan*
[2)] *Graduate School of Comprehensive Rehabilitation, Osaka Prefecture University, Japan*
[3)] *Daiwa House Industry, Japan*
[4)] *Tsubakimoto Chain, Japan*

Abstract. [Purpose] The present study investigated the physical and mental effects of plant factory work in individuals with cervical spinal cord injury and the use of a newly developed agricultural working environment. [Subjects] Six males with C5–C8 spinal cord injuries and 10 healthy volunteers participated. [Methods] Plant factory work involved three simulated repetitive tasks: sowing, transplantation, and harvesting. Surface electromyography was performed in the dominant upper arm, upper trapezius, anterior deltoid, and biceps brachii muscles. Subjects' moods were monitored using the Profile of Mood States. [Results] Five males with C6–C8 injuries performed the same tasks as healthy persons; a male with a C5 injury performed fewer repetitions of tasks because it took longer. Regarding muscle activity during transplantation and harvesting, subjects with spinal cord injury had higher values for the upper trapezius and anterior deltoid muscles compared with healthy persons. The Profile of Mood States vigor scores were significantly higher after tasks in subjects with spinal cord injury. [Conclusion] Individuals with cervical spinal cord injury completed the plant factory work, though it required increased time and muscle activity. For individuals with C5–C8 injuries, it is necessary to develop an appropriate environment and assistive devices to facilitate their work.

Key words: Cervical spinal cord injury, Work, Electromyography

(This article was submitted Oct. 21, 2015, and was accepted Dec. 11, 2015)

INTRODUCTION

Return to work after spinal cord injury (SCI) improves health-related quality of life[1–3)] and is positively associated with psychological adjustment after injury[4, 5)]. In addition, employment of people with SCI has a positive influence on the adjustment of family and social relationships post injury[6, 7)]. Thus, employment is one of the most important goals of rehabilitation after SCI[8)]. However, a review of published studies reported rates of return to work ranging from 21.0–67.0% during 2000–2006[9)]. In particular, employment rates are lower for people with tetraplegia than people with paraplegia[10, 11)], and individuals with severe injury have difficulty in returning to work[12)]. To promote the employment of people with severe disabilities, it is necessary to evaluate their abilities and to provide assistive technology or an appropriate working environment.

If individuals with cervical SCI require a wheelchair, it may not be possible to work in outdoor cultivation. We researched employment opportunities for people with severe disabilities and developed an appropriate environment to make the best use of their talents by utilizing a fully artificial light-type plant factory (hereafter, plant factory). Growing plants indoors enables

*Corresponding author. Satoshi Okahara (E-mail: ai625ai@yahoo.co.jp)

stable and high-speed production that is not affected by the weather; the plants are also highly valuable for use in medicines or health foods, as there is greater quality control with hydroponic culture and availability of nutritional ingredients in a closed indoor space. In addition, high safety can be ensured by cultivating plants in the absence of pesticides in a sterile environment. Furthermore, the plant factory has the advantages of providing employment with stable wages.

To date, we have created a universal design model of the plant factory that enables plants to be cultivated while working in a sitting position for elderly individuals and those with thoracic SCI. We have been developing a welfare-type plant factory that incorporates labor-saving devices and systems and facilitates agricultural employment by including job categories for individuals with cervical SCI.

It is important to consider the influences of working in an environment that is suitable for employment of individuals with SCI. The aim of the present study was to investigate the physical and mental effects of plant factory work in individuals with cervical SCI and to evaluate the use of a newly developed agricultural working environment.

SUBJECTS AND METHODS

Six males with C5–C8 SCI (mean age, 35.8 ± 7.6 years) and a control group of 10 healthy volunteers (mean age, 25.6 ± 10.2 years) participated in this study. According to the American Spinal Injury Association guidelines[13, 14)], the subjects with cervical SCI had upper motor scores ranging from 10 to 40. The inclusion criteria were as follows: (1) ability to use a manual wheelchair, (2) no pain in the shoulder joints, and (3) consented to participate in the study. This study was approved by the Ethics Committee of the School of Comprehensive Rehabilitation, Osaka Prefecture University (2013-119).

The present study investigated upper muscle activity, mood state, and work time during plant factory tasks. The subjects performed the following 3 simulated tasks in the model plant factory, with 150 repetitions of each task: sowing, transplantation, and harvesting. Working time was measured with a stopwatch from the beginning to the end of each task. If subjects took longer than 5 times the duration it took an average healthy person to complete the tasks, the subject performed 50 repetitions of the tasks.

Sowing was performed with seeds for a species of green lettuce (about 0.05 g); subjects planted 150 lettuce seeds in soft urethane foam containing 300 holes in the first 6 of 12 rows from the front within a nursery box (W 600 mm × L 300 mm × H 40 mm). Transplantation involved lettuce seedlings within a soft urethane foam cube (about 10 g); subjects transplanted 150 lettuce seedlings in trays (W 500 mm × L 500 mm × H 60 mm; 9 holes; 4” between centers). In harvesting, which was performed with grown lettuce (about 50 g), subjects simulated harvesting 150 lettuce plants by pretending to cut the bottom of the lettuce in the tray and transferring it to a harvest box located at their side. Subjects used their hands or a spoon for sowing and transplantation and scissors or an imitation cutter for harvesting to ensure safety.

In the laboratory environment of the model plant factory, all work was performed on a bench set to a height of 70 cm so that it could pass through the armrest of a wheelchair, and the space between the bench and subject’s trunk was set to 15 cm. Healthy subjects performed the tasks while sitting in wheelchairs, and those with cervical SCI performed the tasks in their own manual-type wheelchairs. All sessions were performed at a constant ambient temperature of 24 °C, and a person who had more than 3 years of experience in a plant factory supervised the subjects to ensure tasks were performed appropriately.

Surface electromyography (EMG) was recorded using a TeleMyo 2400 G2 Telemetry System and the MyoResearch XP Master analysis software (Noraxon U.S.A., Inc., Scottsdale, AZ, USA) at a sampling frequency of 1.5 kHz. To assess the workload, EMG was recorded from the beginning to completion of each task for 3 muscles in the dominant upper arm: the upper trapezius, anterior deltoid, and biceps brachii muscles. The maximum integrated values 1 second from 5-second maximum voluntary contractions performed against manual resistance were measured twice at the end of an experimental day; these values were used to normalize the percentage of maximum voluntary contraction (%MVC) for rectifying EMG amplitudes of each muscle, and average %MVC values were calculated for each task.

The Profile of Mood States-Short Form (POMS) was used to measure mood states before and after completion of all tasks. Subjects indicated the degree to which each adjective described them at the moment they took the test using a 5-point Likert scale. Scoring of the POMS was classified into 6 psychological subscales: fatigue-inertia, vigor-activity, tension-anxiety, depression-dejection, anger-hostility, and confusion-bewilderment; each T-score and change value were calculated.

Statistical analysis of differences in work time, EMG parameters, and POMS scores were compared among all subjects using the Wilcoxon signed-rank test and were compared between healthy subjects and those with cervical SCI using the Mann-Whitney U-test. Significance was set at $p < 0.05$.

RESULTS

The subjects’ characteristics (healthy group, n = 10; SCI group, n = 6) are presented in Table 1. The 10 healthy subjects and 5 of the individuals with cervical SCI (C6–C8) were able to complete 150 repetitions of each plant factory task. One individual with a C5 injury completed only 50 repetitions of the transplantation and harvesting tasks because he took 9–10 times longer than a healthy person. The working time for subjects with C6–C8 injuries was about 2–3 times longer for each task than that for healthy subjects ($p < 0.05$).

Regarding muscle activity in transplantation and harvesting, individuals with cervical SCI had higher average %MVC values of the upper trapezius and anterior deltoid muscles compared with healthy persons, and the difference in the anterior deltoid during harvesting was statistically significant ($p < 0.05$; Table 2).

The tension-anxiety and vigor POMS scores were significantly decreased in the healthy group ($p < 0.05$), and the vigor POMS score was significantly increased in the cervical SCI group ($p < 0.05$; Table 3). When comparing scores between healthy subjects and those with cervical SCI, there was a significant difference in the vigor subscale as assessed by the Mann-Whitney U-test ($p < 0.05$).

Table 1. Subject characteristics

	Healthy group (n=10)	Cervical SCI group (n=6)
Gender (male / female)	6 / 4	6 / 0
Age (years)	25.6 ± 10.2	35.8 ± 7.6
Height (cm)	168.3 ± 10.5	174.5 ± 4.2
Weight (kg)	64.1 ± 15.2	55.5 ± 11.3
Body mass index (kg/m^2)	22.5 ± 4.1	18.2 ± 3.6
ASIA motor score of upper extremity (/50)	-	23.0 ± 11.5

Values are presented as the mean ± SD, with the exception of gender.
ASIA: American Spinal Injury Association; SCI: spinal cord injury

Table 2. Average percentage of maximum voluntary contraction (%MVC) during plant factory tasks

	Healthy group (n=10)	Cervical SCI group (n=6)
Sowing		
UT	8.8 ± 4.4	10.4 ± 6.2
AD	7.8 ± 4.4	8.0 ± 3.2
BB	3.8 ± 1.8	2.2 ± 1.2
Transplanting		
UT	11.4 ± 4.7	13.5 ± 6.3
AD	11.3 ± 4.3	17.2 ± 13.6
BB	5.1 ± 2.0	3.0 ± 1.5
Harvesting		
UT	12.3 ± 5.5	17.1 ± 7.7
AD	8.7 ± 3.7*	20.3 ± 14.5*
BB	3.8 ± 1.8	4.0 ± 2.4

Values are presented as the mean ± SD.
*$p < 0.05$ by Mann-Whitney U test
UT: upper trapezius; AD: anterior deltoid; BB: biceps brachii; SCI: spinal cord injury

Table 3. Comparison of the Profile of Mood States scores before and after completion of plant factory tasks

	Healthy group (n=10)		Cervical SCI group (n=6)	
	Before	After	Before	After
Tension-anxiety	39.7 ± 4.1*	35.8 ± 2.9*	36.5 ± 4.5	38.3 ± 5.8
Depression	42.5 ± 3.9	40.7 ± 2.7	41.7 ± 2.9	41.7 ± 2.4
Anger-hostility	39.1 ± 4.2	37.8 ± 2.5	38.8 ± 3.0	37.0 ± 0
Vigor	46.1 ± 10.7*	39.8 ± 9.0*	36.8 ± 7.4*	42.5 ± 9.4*
Fatigue	37.4 ± 3.3	38.8 ± 2.7	38.0 ± 3.7	45.5 ± 5.8
Confusion	49.4 ± 10.0	44.1 ± 2.9	46.0 ± 2.8	43.5 ± 2.3

Values are presented as the mean ± SD.
*$p < 0.05$ by Wilcoxon signed-rank test
SCI: spinal cord injury

DISCUSSION

Individuals with cervical SCI completed the plant factory tasks, though it required increased time and muscle activity. For individuals with C5–C8 injuries, it is important to develop an appropriate environment and assistive devices to facilitate work because they have not only trunk paralysis but also upper extremity weakness and dysfunction. In particular, we think that it is necessary to devise work that can be easily and closely performed for people with a C5 injury because dysfunction in finger dexterity and distal reaching result in tasks taking a long time to complete.

From the results of surface EMG of individuals with cervical SCI, activity values of the upper trapezius and anterior deltoid muscles in the elevated upper limb showed more than 15%MVC during the transplantation and harvesting tasks. According to a study by Madeleine, muscle fatigue and musculoskeletal discomfort can be a precursor of pain related to work-related musculoskeletal disorders[15]. Thus, it is necessary to establish reduced muscle activity. Accordingly, we developed an environment that allows workers to put down their forearms during work, and we also developed a handy tool that may be utilized using gross motions. For example, to avoid elevating the upper limbs, it is possible to use a turntable under a tray, which can easily be placed in front of the body for transplanting, and palm-sized equipment consisting of safety razors can be used for harvesting with a simple sliding motion. If plant factory work is simplified through the use of assistive devices, the work time will shorten. Work pace is a key issue in production system design[16–20]; improvement of work efficiency may also prevent additional work-related musculoskeletal disorders.

The positive physiological and emotional effects of walking in a forest and horticultural therapy have previously been reported[21, 22]. We confirmed that individuals with cervical SCI had improved vigor after plant factory work, with predicted positive psychological aspects. However, individuals with cervical SCI had increased tension and anxiety and fatigue scores; therefore, it is necessary to consider the long-term psychological effects of performing delicate tasks in a closed space.

Many reports have demonstrated low physical activity and energy consumption per day in individuals with SCI[23, 24]. In particular, the prevalence of cardiovascular disease is increased in people with SCI[23, 24]. Since there is a high possibility that the cause of death in those with SCI may be related to chronic lack of exercise, increasing opportunities to work may be expected to improve physical activities and psychological well-being.

Therefore, although automation is possible for nearly all tasks, by application of designs and appropriate automation and manual work, we believe that manual work in a welfare-type plant factory is important given the physical and mental benefits of directly touching and working with green plants. The limitations of this study include the small sample size and the influence of long-term plant factory work on cervical SCI.

By finding employment, it is possible for individuals to increase their income and enhance their quality of life, and physical, mental, and social rehabilitation can be expected. The results of this study are highly useful and are directly linked to the practical application of plant factories; the newly proposed working environment can facilitate employment of individuals with severe SCI and improve their quality of life.

REFERENCES

1) Lidal IB, Veenstra M, Hjeltnes N, et al.: Health-related quality of life in persons with long-standing spinal cord injury. Spinal Cord, 2008, 46: 710–715. [Medline] [CrossRef]
2) Leduc BE, Lepage Y: Health-related quality of life after spinal cord injury. Disabil Rehabil, 2002, 24: 196–202. [Medline] [CrossRef]
3) Westgren N, Levi R: Quality of life and traumatic spinal cord injury. Arch Phys Med Rehabil, 1998, 79: 1433–1439. [Medline] [CrossRef]
4) Krause JS: Adjustment to life after spinal cord injury: a comparison among three participant groups based on employment status. Rehabil Couns Bull, 1992, 35: 218–229.
5) Gurcay E, Bal A, Eksioglu E, et al.: Quality of life in patients with spinal cord injury. Int J Rehabil Res, 2010, 33: 356–358. [Medline] [CrossRef]
6) Krause JS: Employment after spinal cord injury: transition and life adjustment. Rehabil Couns Bull, 1996, 39: 244–255.
7) Suttiwong J, Vongsirinavarat M, Vachalathiti R, et al.: Impact on participation and autonomy questionnaire: psychometric properties of the thai version. J Phys Ther Sci, 2013, 25: 769–774. [Medline] [CrossRef]
8) Wood-Dauphinée S, Exner G, Bostanci B, et al. SCI Consensus Group: Quality of life in patients with spinal cord injury—basic issues, assessment, and recommendations. Restor Neurol Neurosci, 2002, 20: 135–149. [Medline]
9) Lidal IB, Huynh TK, Biering-Sørensen F: Return to work following spinal cord injury: a review. Disabil Rehabil, 2007, 29: 1341–1375. [Medline] [CrossRef]
10) Krause JS, Anson CA: Employment after spinal cord injury: relation to selected participant characteristics. Arch Phys

Med Rehabil, 1996, 77: 737–743. [Medline] [CrossRef]
11) Pflaum C, McCollister G, Strauss DJ, et al.: Worklife after traumatic spinal cord injury. J Spinal Cord Med, 2006, 29: 377–386. [Medline]
12) Ottomanelli L, Lind L: Review of critical factors related to employment after spinal cord injury: implications for research and vocational services. J Spinal Cord Med, 2009, 32: 503–531. [Medline]
13) Maynard FM Jr, Bracken MB, Creasey G, et al. American Spinal Injury Association: International standards for neurological and functional classification of spinal cord injury. Spinal Cord, 1997, 35: 266–274. [Medline] [CrossRef]
14) Ditunno JF Jr, Young W, Donovan WH, et al. American Spinal Injury Association: The international standards booklet for neurological and functional classification of spinal cord injury. Paraplegia, 1994, 32: 70–80. [Medline] [CrossRef]
15) Madeleine P: On functional motor adaptations: from the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. Acta Physiol (Oxf), 2010, 199: 1–46. [Medline] [CrossRef]
16) Bosch T, Mathiassen SE, Visser B, et al.: The effect of work pace on workload, motor variability and fatigue during simulated light assembly work. Ergonomics, 2011, 54: 154–168. [Medline] [CrossRef]
17) Nur NM, Dawal SZ, Dahari M, et al.: Muscle activity, time to fatigue, and maximum task duration at different levels of production standard time. J Phys Ther Sci, 2015, 27: 2323–2326. [Medline] [CrossRef]
18) Yoo WG: Effect of resting in a chair, resting with range of motion exercises, and back strengthening exercises on pain and the flexion-relaxation ratio of computer workers with low back pain. J Phys Ther Sci, 2014, 26: 321–322. [Medline] [CrossRef]
19) Lee JH, Gak HB: Effects of self stretching on pain and musculoskeletal symptom of bus drivers. J Phys Ther Sci, 2014, 26: 1911–1914. [Medline] [CrossRef]
20) Nur NM, Dawal SZ, Dahari M, et al.: The effects of energy expenditure rate on work productivity performance at different levels of production standard time. J Phys Ther Sci, 2015, 27: 2431–2433. [Medline] [CrossRef]
21) Li Q, Morimoto K, Kobayashi M, et al.: A forest bathing trip increases human natural killer activity and expression of anti-cancer proteins in female subjects. J Biol Regul Homeost Agents, 2008, 22: 45–55. [Medline]
22) Verra ML, Angst F, Beck T, et al.: Horticultural therapy for patients with chronic musculoskeletal pain: results of a pilot study. Altern Ther Health Med, 2012, 18: 44–50. [Medline]
23) Gorgey AS, Dolbow DR, Dolbow JD, et al.: Effects of spinal cord injury on body composition and metabolic profile—part I. J Spinal Cord Med, 2014, 37: 693–702. [Medline] [CrossRef]
24) Bauman WA, Spungen AM: Coronary heart disease in individuals with spinal cord injury: assessment of risk factors. Spinal Cord, 2008, 46: 466–476. [Medline] [CrossRef]