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Development and Assessment of Shovel Applying Foothold

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Objective: The aim of this study is to develop a farming shovel to reduce workload, which helps farmers lower the risk of musculoskeletal disease.

Background: Most of work using farming tools including shovels requires repetitive works and awkward postures on body parts, and it could possibly cause work-related musculoskeletal disorders. It is necessary to develop and distribute farm equipment and tools in order to reduce physical workload.

Method: To improve the most uncomfortable task perceived by ten farmers during the work with a shovel, the improved shovel was designed and made as a prototype for experiment for the comparison of the existing and improved shovels. Twenty males were recruited for this experiment, and muscle activity (%MVC) of six body parts and subjective discomfort ratings by body parts while working with a shovel were measured. A paired *t*-test was performed to compare physical workload between the existing shovel and the developed one.

Results: A shovel applying foothold tied between shaft and blade was designed, which can help workers reduce repetitive bending of back and pressures for upper limbs while digging soil. According to compared evaluation of the developed shovel and the existing shovel, the developed shovel's %MVCs in all experimental muscles were significantly lower than those of the existing shovel. The developed shovel showed the biggest drop in perceived subjective discomfort rating of back, followed by arm and neck, compared to the existing shovel.

Conclusion: It was confirmed that attaching a foothold to a shovel was an effective way of reducing workload in back and upper limbs during digging.

Application: In the near future, if we put the prototype of developed shovel to practical use after making up for defects, it will help farm work environment be healthier and safer.

Keywords: Shovel, Foothold, EMG, Farmer

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1. Introduction

Musculoskeletal disorders take up the highest ratio among the occupational diseases occurring to farmers (KOSIS, 2015). The aging problem of farming population is serious (Statistics Korea, 2010), and farming workplace mostly comprised of the natural environment has limitations in improving the working environment. Although manual work has sharply decreased, due to mechanization in many aspects in farming villages, compared to the past, various chronic diseases, of which causes are

uncomfortable postures, repetitive motions and the excessive use of force appear, appear in view of agricultural characteristics (Park et al., 1994). Farming tasks in particular are labor-intensive, and the content and methods of the tasks are not standardized, they are non-continuing work, and are concentrated during the specific period; therefore, musculoskeletal disorders are highly likely to be caused. Together with recent new agricultural technological advancement, farming work duration increases, and the seriousness of musculoskeletal disorders has recently become higher, owing to farming population's aging, increase in female farmers and workload augmentation according to lacking labor force (Son and Sin, 2009).

Most farming tools used for the improvement farming work convenience have improved of late in consideration of farming worker's ergonomic aspect, and new type of tools are developed. The reduction of workload burden and work efficiency improvement are implemented through the farming work safety model village pilot project or convenience equipment support project of the Rural Development Administration. Most farmers, however, are exposed to uncomfortable working postures and working environment, where repetitive work occurs. Almost all the farming manual tools have a straight pattern. Therefore it is difficult to maintain proper working posture according to work type, and unreasonable burdens are caused to muscles and joints, because wrist, arm, shoulder and back are twisted and bent.

Upon looking at previous studies to enhance farming work safety and convenience, there are following studies: studies on identifying the causes of musculoskeletal disorders in farming work, and suggesting improvement principles (Jeong and Kim, 2011; Jung, 2011), researches on offering ergonomic improvement cases regarding the convenience tools for farming work (Lee et al., 2010; Kee et al., 2011), studies on developing convenience tools for farming work or on evaluating developed or improved tools' efficiency (Lim et al., 2014; Lee et al., 2010; Jung and Jung, 2007; Ha et al., 2012). Studies on shovels among the farming tools include an ergonomic study on working postures and burdens using a shovel (Sin, 2000), and a study on shovel's design improvement to minimize physical discomfort and cumulative external injuries (Lee, 2001), and they are insufficient. Actually, research achievements can hardly be found recently.

This study draws the improvement of work that uses an existing shovel targeting farmers, proposes improved shovel's design, manufactures a prototype, and comparatively evaluates the use effects of the existing and developed shovels.

2. Method

2.1 Design and manufacture of improved shovel

To draw the development merits of a shovel that can reduce workload, the farms of ten farmers selected through non-probability sampling were visited in this study, and a questionnaire survey on discomforts subjectively perceived from the work using the existing shovel was carried out. An existing shovel was defined as the one with KS B7351 (Shovel and Scoop) Standard.

The survey details consisted of four item: the feeling of handle grip, burden to body upon digging soil, fatigue by repetitive work and the thickness of shovel shaft. Discomfort was measured with the scale from very comfortable (1 point) to very uncomfortable (5 points). The higher the score is, the more discomfort is perceived.

This study designed the developed shovel, focused on improving the most uncomfortable factors targeting the farmers. Based on the design, a prototype was manufactured for a workload improvement effect evaluation experiment between the existing and the developed shovels. Using the shovel attached with wooden shaft with triangle-shaped handle sold in the market, a type attaching the foothold in the connecting part of blade and shaft developed in this study was selected. The reason is that it is easy to equally control the size and shape of blade, shaft and handle that can affect the comparative evaluation experiment with the existing product.

2.2 Evaluation experiment of use effect

2.2.1 Subjects

The subjects were 20 adult males without the experience of musculoskeletal symptoms. Before the experiment, the purpose and procedure of the experiment were explained for them to participate in the experiment. The mean age of the subjects were 27.5±3.34, and the mean height and weight were 173.42±5.54cm and 71.4±4.24kg, respectively.

2.2.2 Experiment design

Table 1 shows the combination of the existing and developed shovels to comparatively evaluate the workloads of them. The material of the shaft was wood, blade's shape was round, and handle's shape was triangle, which were the same between the existing and developed shovels. As for the length of shaft, existing shovel shaft's length was 67cm, and the developed shovel shaft's length was 74cm. The shaft length of the developed shovel's prototype was extended by attaching the foothold. The comparative evaluation items were muscle activity (%MVC) and subjective discomfort rating. The muscles to measure muscle activity were six parts: erector spinae (left and right), biceps brachii (left and right) and deltoid (left and right). As for subjective discomfort rating, 5-point scale on neck, shoulder, arm, back and hand were used: very comfortable (1 point) to very uncomfortable (5 points). The higher the score is, the higher discomfort is perceived.

Table 1. Experimental design

	Existing shovel	Developed shovel
Shaft material and size	Wood, 67cm	Wood, 74cm
Blade style	Slightly curved scoop with upturned edges and a pointed center	Slightly curved scoop with upturned edges and a pointed center
Handle style	D-handle	D-handle
Picture of experiment		

2.2.3 Experiment method

This study carried out mockup work in which the blade was pressed into soil and soil was scooped up as an experiment to comparatively evaluate the workloads of the existing and developed shovels. An outdoor experiment was performed to set the working environment similar to the actual working environment to the fullest. To make working conditions equal to all the subjects, they were instructed to grab the shaft of the shovel with left hand, and hold the shovel's handle with right hand. Mean muscle activity (%MVC) and subjective discomfort rating were measured, while the subjects conducted ten times of the task at the designated location per experiment (two times of experiments in total per subject), and 5-min break was given to them between

the experiments (Figure 1).

The data measured through the experiment, the SPSS PC (ver. 18.0) was used. After mean and standard deviation were calculated in order to identify the difference in workload between the existing and developed shovels, this study conducted a paired *t*-test comparing the difference between groups was performed.

3. Results

3.1 Evaluation of workload of existing shovel and drawing improvement

This study carried out a survey by visiting farms to identify the types of shovels used for farming, and discomforts upon using a shovel. A shovel is a tool used for digging or scooping up soil. Concerning the most general shovel's shape, a metal-blade is attached to wooden shaft, and at the end of the shaft, there is a triangular handle. General work using a shovel is to dig with shovel blade and shaft, and scoop up soil with the strength of arm. As a result of surveying subjectively perceived discomfort by ten farmers in the work using a shovel, the burden to body upon scooping up soil was the most uncomfortable, followed by fatigue by repetitive work, the thickness of handle and the grip of the handle (Figure 1). This study selected the factor to reduce physical burden upon scooping up soil felt the most uncomfortably as the matter to improve the shovel.

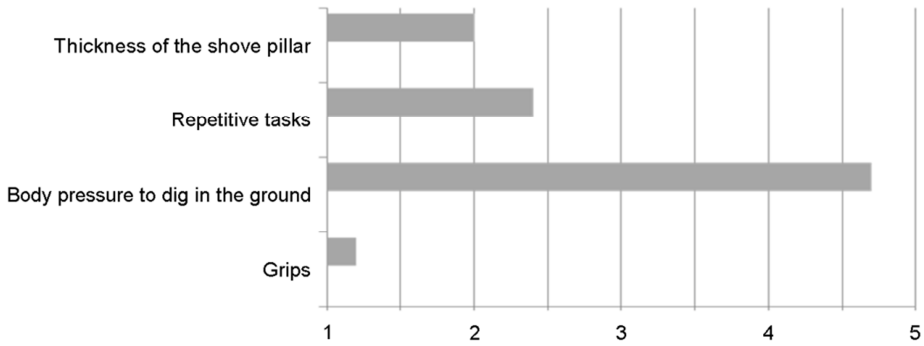

Figure 1. Subjective discomfort ratings for existing shovel [very comfortable (1) ~ very uncomfortable (5)]

3.2 Design of foothold-attached shovel and manufacture of prototype

This study designed an improved shovel, focused on the improvement of repetitive bending of back caused by task scooping up soil with the strength of arm, while pressuring the existing shovel blade into the ground, and on repetitive burden improvement of arm pressuring the shovel shaft. To minimize bending angle of back and load to arm, this study designed a foothold with elastic auxiliary material at the location connecting shovel blade and shovel shaft. By installing the foothold auxiliary material at the point connecting the blade and shaft, the foothold-attached shovel can reduce workload and help efficient work by delivering the force of worker to the shovel's center. The shovel reduces burdensome work of repetitive back bending, and makes comfortable and prompt work possible. The connection part of the shovel is connected with a hinge so that the working part can rotate, and it also includes the fixing part for the working part to be fixed and the foothold to be located at the connection part. By attaching the foothold protruded to one vertical direction from the direction of the shovel shaft, this study connected with the shovel shaft with elastic auxiliary material for the foothold to be precisely return to its original location. When a worker gives force by placing

a foot on the foothold, a function that easily scoops up soil without bending back to the fullest is offered. The prototype manufactured according to the design drawing was completed through application of the foothold to wooden shovel shaft to which a triangular handle is used the most commonly (Figure 2).

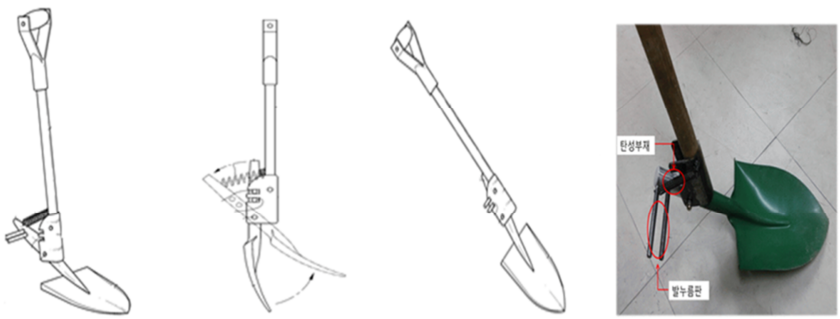

Figure 2. Design and prototype of the shovel applying foothold

3.3 Comparative evaluation result of muscle activity (%MVC) and subjective discomfort ratings between existing and developed shovels

3.3.1 Comparative evaluation result of workload using muscle activity (%MVC)

As a result of comparative evaluation of %MVCs of the existing and improved shovels, the improved shovel showed lower %MVCs than those of the existing shovel in all erector spinae, biceps brachii and deltoid (left and right), and statistically significant differences were revealed. Concerning erector spinae (both left and right), the muscle activity (%MVC) was remarkably lower in the improved shovel, compared to the existing shovel (Table 2).

Table 2. %MVCs of each muscle groups

Type / Muscle	Existing shovel		Developed shovel		T-value
	Mean	SD	Mean	SD	
Biceps brachii (R)	40.02	3.44	20.02	1.06	24.535***
Biceps brachii (L)	37.78	2.38	22.18	2.66	22.651***
Deltoid (R)	34.63	4.38	25.44	2.10	9.674***
Deltoid (L)	41.62	2.28	21.06	1.13	37.079***
Erector spinae (R)	46.54	2.47	23.35	1.50	39.968***
Erector spinae (L)	48.30	1.81	21.03	1.53	48.328***

R: Right, L: Left, ***$p<0.001$

3.3.2 Comparative evaluation of subjective discomfort ratings

Table 3 shows the comparative evaluation result of discomfort ratings by body part subjectively perceived by each subject upon using the existing shovel and the foothold applying improved shovel. The subjective discomfort rating on back sharply declined, and those of arm and neck also fell, and they showed significant differences.

Table 3. Subjective discomfort ratings by body parts

Type / Muscle	Existing shovel		Developed shovel		T-value
	Mean	SD	Mean	SD	
Neck	2.7	0.48	2.3	0.68	2.449*
Shoulder	3.1	0.74	2.6	0.52	1.861
Arm	3.4	0.52	2.2	0.63	4.129**
Back	4.6	0.52	1.9	0.32	12.650***
Hand	2.8	0.42	2.9	0.57	-0.429

very comfortable (1) ~ very uncomfortable (5), ***$p<0.001$, **$p<0.01$, *$p<0.05$

4. Conclusion

This study designed an improved shovel to reduce workload of a shovel used in farming work, manufactured a prototype, and comparatively evaluated the workloads between the existing and improved shovels.

According to the survey result of subjective discomforts perceived by using the existing shovel targeting farmers, they replied the burdens to body parts were the biggest in scooping up soil. Therefore, this study made a design of a foothold applying shovel to reduce burden to back, when one scoops up soil, and manufactured a prototype.

As a result of muscle activity (%MVC) evaluation in farming work using the existing and improved shovels, the lower %MVC was shown in the work using the improved shovel in all muscles. The reason seems that the motion of pressuring the existing shovel blade into the ground and scooping up soil by bending back is replaced by the motion of stepping on the foothold using the improved shovel. Upon looking into the result of surveying the subjective discomfort ratings, lower discomfort ratings were shown in the developed shovel in the back, neck and arm, which implies the effect of the attached foothold. Especially, the biggest reduction effect on the back was revealed, and thus the burden in scooping up soil sharply fell in using the foothold applying shovel.

The limitation of this study is that quantitative evaluation on various motions is required, since shovel-using tasks cannot be conducted with the same motions. In addition, the burden by weight cannot be ignored regarding repetitive work for a long time, because the weight of the foothold and connection device are added to the existing shovel, which is conjectured to be a matter to consider.

There is a need to supplement the prototype of the developed shovel, and promote the commercialization of it to diffuse such a shovel to farmers in the near future. The findings in this study are anticipated to contribute to the improvement and development

research of convenience equipment to prevent farmers' musculoskeletal disorders, and to the farming environment improvement.

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