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POWER SURGE TOOL LINE의 인간공학적 평가에 관한 연구

Ergonomic Evaluation of The POWER SURGE TOOL LINE

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ABSTRACT

The objective of this study was to evaluate quantitatively the effects of handle types of garden tools on the ergonomic effectiveness, user satisfaction in terms of work performance, and subjective judgment of tactile feel and control. The approach was to compare garden tools with conventional wood handle and newly developed fiberglass handle, and to utilize three different tools: shovel, rake, and hoe. The hollow fiberglass handle was 12% more efficient than either the wood or solid fiberglass handle. The next important measure was the subjective ratings of the perceived exertion averaged across three different tools. The average ratings for the hollow fiberglass handle were the smallest. In conclusion, the hollow fiberglass handle showed better efficiency and better subjective acceptability for comfort, tactile feel, and especially decreased slipperiness.

국 문 초 록

본 연구의 목적은 수공구 손잡이의 재질과 형태가 작업 성능과 소비자 만족도에 미치는 영향을 정량적으로 평가하는데 있다. 본 연구는 삽, 써래, 괭이 등 수공구의 손잡이에 기존의 목재를 사용한 것과 fiberglass를 사용한 것을 인간공학적 척도로 비교 분석하였다. 연구 결과 fiberglass 재질의 홈이 파진 손잡이를 사용한 수공구가 기존의 목재 손잡이를 사용한 수공구보다 약 12% 효율적이며, 소비자의 만족도 면에서도 우수한 것으로 나타났다.

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1. Introduction

Basic garden tools such as the shovel, rake, and hoe have evolved over many years of use in various different applications. Although these tools are very familiar in our daily life, the basic design of garden tools has not changed significantly over the past years. In this regard, Freivalds stated that the discussion of ergonomic principles in shovel design has been generally omitted because of the belief that the thousands of years of experience applied to such a common tool would have produced an implement optimally suited to human use[1,2]. Although the concepts of human performance and ergonomic efficiency have been applied to the design stage of hand tools, and these designs are basically sound, there is still considerable room for improvement to adapt the hand tools optimally for human use. For example, there are some indications that modifying tool handles may improve shoveling performance by reducing the amount of stooping or bending required[3].

There are a number of variables and guidelines that must be considered to design hand tools[4]. These are mainly based on the biomechanical principles and include such factors as shape, size, weight, length, thickness, and texture[5]. The few studies that have examined the tool handle have primarily looked into force production as a function of the shape of the handle[6,7], the type of surface[8] or the type of texture[9].

A somewhat new approach in hand tool design in which handle material is considered has been introduced by Fellow and Freivalds[10]. In their study, the use of a foam rubber grip attached over the hand tool resulted in significantly better subjective measures of hand/forearm fatigue and hand tenderness over the traditional wood grip and showed the uniformity of the force distribution. Thus, they concluded that uniform force distribution provided by the foam grip should positively affect consumer performance and satisfaction with the tools. However, no one has quantitatively examined the effects of handle materials themselves on both a person's performance capability and biomechanical stress on the human body.

Traditionally, wood has been used for most garden tool handles without any consideration for the diversity of available materials. Nevertheless, fiberglass has lately emerged as a material that can be appropriate for garden tool handles. Recently, the True Temper company has developed garden tools with fiberglass handles. Since it seems that fiberglass may be the handle material of the future because of its characteristics such as lightness, ease of production, and flexibility, there is a need for study about how the fiberglass handle affects worker's performance in terms of biomechanics, how the worker feels about this handle tactually, and whether this handle fits well with human hand or not in terms of ergonomics.

The purpose of this study was to evaluate quantitatively the effects of handle types of garden tools on the ergonomic effectiveness, user satisfaction in terms of work performance, and subjective judgment of tactile feel and control.

2. Methods

2.1 Subjects

Five male and five female subjects, with attributes summarized in Table 1, were participated in this study. All subjects were students who volunteered for the study and were paid appropriately for their work. Prior to the experiment, they were screened by a questionnaire for back and hernia problems. They were all in good physical condition and had some experience in using gardening tools.

Table 1 Distribution of subjects' attribute

Attribute	Males			Females		
	Mean	SD	Range	Mean	SD	Range
Age(years)	26.4	1.1	25-28	25.8	4.3	21-30
Height(cm)	172.8	3.7	169-178	156	8.5	148-167
Weight(kg)	67.6	7.4	55-74	50.2	4.1	44-55

2.2 Procedure

Three different garden tools such as shovel, rake and hoe, and three different handles such as wood, solid fiberglass and hollow fiberglass were used in the study. Their characteristics are summarized in Table 2. Garden tools with wood handle were commercial ones while those with solid and hollow fiberglass handle were recently developed. As their names indicated, fiberglass handles are made of fiberglass and they are divided into solid fiberglass handle and hollow fiberglass handle according to their surface type. The solid fiberglass handle has a smooth surface and the hollow fiberglass handle has one half of the round cross section of the handle being smooth, the other half being ribbed.

Table 2 Characteristics of the garden tools

Tool	Handle	Weight (kg)	Length (cm)		Handle diameter(cm)		Grip
			Whole	Handle*	Left	Right	material
Rake	Wood	0.85	136.5	118.5	3.3	3.0	wood
	Solid	1.25	145.5	120.0	3.3	3.7	fiberglass
	Hollow	1.05	146.5	127.0	3.0	3.3	foam
Hoe	Wood	0.95	136.0	118.0	3.2	2.6	wood
	Solid	1.30	140.0	115.0	3.3	3.7	fiberglass
	Hollow	1.05	147.0	127.0	2.8	3.3	foam
Shovel	Wood	1.80	150.0	102.5	3.8	2.8	wood
	Solid	1.80	149.0	101.5	3.3	3.7	fiberglass
	Hollow	1.80	148.0	98.0	3.2	3.7	foam

* Tool length without blade

Subjects were given three different but generalized tasks and corresponding tools. They were instructed to grasp the tool and to start the task in the specific manner. The task varied between tools. Each tool was analyzed with handle types.

The shoveling task consisted of scooping foundry casting sand from one barrel and throwing it into another barrel at a distance of 1.0 m. A shovel randomly selected was given to the subject and he/she shoveled for one minute at a rate of 18 cycles per minute. The raking and hoeing tasks also involved moving the same sand as shoveling tasks at the floor level in a standard manner. These tasks were performed at 20 cycles per minute. A metronome was used to set and maintain the desired pace.

One minute of work per tool and handle combinations was followed by two minutes of rest before another set of experiment started. In rest period, heart rate was checked to be normal. After experiment, subjects were asked to perform the subjective judgment of overall perceived handle discomfort, lack of tactile feel, and handle slipperiness.

2.3 Measurement

Four different dependent measures were utilized to evaluate tools: 1) shoveling performance-amount of work performed, 2) hand grip force and EMG of the arm muscles, 3) task workload-measured by change in subject's heart rate, and 4) subjective ratings of perceived exertion-for overall handle discomfort, lack of tactile feel, and handle slipperiness.

Shoveling performance was calculated from the amount of sand placed in the barrel per unit time. The amount of grip force was measured on typical tasks for each of different tool and handle combinations. Four UniForce sensors, developed by Force Imaging Technologies, were placed on the right and left hand each to measure the compressive force occurred between hand and tool handle during the experiment. Two force sensors of right hand were on the palm side of metacarpal joint of index and middle finger and those of left hand were also on the same location as the right hand. The location of sensors was determined by a pilot study. To minimize between subject differences, the grip forces were normalized.

Values of EMG, which are a traditional indirect measure of force requirements of active muscles, were recorded from the flexor digitorum superficials(FDS) as well as from the biceps brachii (BB) for both arms. FDS is one of the forearm muscle and utilized in grasping the tool while BB is the upper arm muscle utilized in holding the tool. To eliminate any effect on background noise and minimize between subject and electrode differences, EMG was normalized. Grip force and EMG were measured simultaneously by using FlexComp system, developed by Thought Technology.

Heart rate was recorded before and after experiment each using Favor heart rate monitor. Then the difference between before and after experiment, that is, an increase in heart rate, was used as an indicator of task workload during the experiment.

Subjective ratings of perceived exertion for overall handle discomfort, lack of tactile feel, and handle slipperiness were measured. Borg's CR-10 scale, ranging from 0 (nothing at all) to 10 (extremely strong, almost maximum), was used. In this scale, a lower number means more comfortable of acceptable[11]. Rating values were also normalized in order to reduce the effect of individual variations in baseline subjectivity.

3. Results

All results averaged over subjects are given in Table 3 and Table 4 from three different tools and three different handles. All statistical analyses were performed by MINITAB statistical analysis package. Results are described in detail for only one tool, the shovel, because only the shovel showed the significant differences between handles. However, the result of subjective ratings of perceived exertion is presented for all tools. Overall, the other tools such as rake and hoe, for most part, showed very similar results to the shovel.

Table 3 Results averaged over subjects (means and SD)-Grip force and EMG

Tool	Handle	Normalized grip force				Normalized EMG			
		Left-I[1]	Left-M[2]	Right-M	Right-I	Left-FDS	Left-BB	Right-FDS	Right-BB
Shovel	Wood	0.64* (0.13)	0.79* (0.09)	0.61 (0.27)	0.62 (0.13)	0.65 (0.13)	0.65** (0.14)	0.55* (0.18)	0.62* (0.20)
	Solid	0.62* (0.14)	0.52** (0.21)	0.67 (0.14)	0.57 (0.19)	0.63 (0.13)	0.53** (0.17)	0.42* (0.17)	0.51* (0.20)
	Hollow	0.47* (0.17)	0.33** (0.17)	0.51 (0.23)	0.59 (0.21)	0.60 (0.13)	0.51** (0.13)	0.39* (0.17)	0.49* (0.19)
Rake	Wood	0.54 (0.27)	0.35 (0.19)	0.39 (0.19)	0.41 (0.25)	0.43 (0.16)	0.41 (0.12)	0.31* (0.21)	0.37 (0.22)
	Solid	0.49 (0.16)	0.34 (0.19)	0.41 (0.13)	0.50 (0.18)	0.37 (0.11)	0.41 (0.17)	0.21* (0.13)	0.27 (0.17)
	Hollow	0.52 (0.20)	0.30 (0.12)	0.51 (0.27)	0.48 (0.23)	0.38 (0.21)	0.42 (0.18)	0.23* (0.11)	0.31 (0.25)
Hoe	Wood	0.50 (0.17)	0.24 (0.11)	0.43 (0.18)	0.48 (0.18)	0.44 (0.24)	0.48 (0.23)	0.32 (0.23)	0.28 (0.14)
	Solid	0.47 (0.20)	0.28 (0.10)	0.49 (0.20)	0.47 (0.18)	0.44 (0.22)	0.48 (0.17)	0.29 (0.20)	0.27 (0.16)
	Hollow	0.50 (0.17)	0.23 (0.07)	0.42 (0.22)	0.41 (0.13)	0.40 (0.10)	0.42 (0.18)	0.31 (0.19)	0.24 (0.14)

* =significant at $p<0.05$, ** =significant at $p<0.01$
[1] =index finger, [2] =middle finger

An analysis of variance(ANOVA) was performed on all dependent measures for all tools and handles. In case of grip force exerted and normalized EMG, ANOVA showed that results for all tools were very similar except for the onnaire for back and hernia problems. They were all in good physical condition and had some experience in using gardening tools.

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Shovel	Wood	1.80	150.0	102.5	3.8	2.8	wood
	Solid	1.80	149.0	101.5	3.3	3.7	fiberglass
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Table 3 Results averaged over subjects (means and SD)-Grip force and EMG

Tool	Handle	Normalized grip force				Normalized EMG			
		Left-I[1]	Left-M[2]	Right-M	Right-I	Left-FDS	Left-BB	Right-FDS	Right-BB
Shovel	Wood	0.64* (0.13)	0.79* (0.09)	0.61 (0.27)	0.62 (0.13)	0.65 (0.13)	0.65** (0.14)	0.55* (0.18)	0.62* (0.20)
	Solid	0.62* (0.14)	0.52** (0.21)	0.67 (0.14)	0.57 (0.19)	0.63 (0.13)	0.53** (0.17)	0.42* (0.17)	0.51* (0.20)
	Hollow	0.47* (0.17)	0.33** (0.17)	0.51 (0.23)	0.59 (0.21)	0.60 (0.13)	0.51** (0.13)	0.39* (0.17)	0.49* (0.19)
Rake	Wood	0.54 (0.27)	0.35 (0.19)	0.39 (0.19)	0.41 (0.25)	0.43 (0.16)	0.41 (0.12)	0.31* (0.21)	0.37 (0.22)
	Solid	0.49 (0.16)	0.34 (0.19)	0.41 (0.13)	0.50 (0.18)	0.37 (0.11)	0.41 (0.17)	0.21* (0.13)	0.27 (0.17)
	Hollow	0.52 (0.20)	0.30 (0.12)	0.51 (0.27)	0.48 (0.23)	0.38 (0.21)	0.42 (0.18)	0.23* (0.11)	0.31 (0.25)
Hoe	Wood	0.50 (0.17)	0.24 (0.11)	0.43 (0.18)	0.48 (0.18)	0.44 (0.24)	0.48 (0.23)	0.32 (0.23)	0.28 (0.14)
	Solid	0.47 (0.20)	0.28 (0.10)	0.49 (0.20)	0.47 (0.18)	0.44 (0.22)	0.48 (0.17)	0.29 (0.20)	0.27 (0.16)
	Hollow	0.50 (0.17)	0.23 (0.07)	0.42 (0.22)	0.41 (0.13)	0.40 (0.10)	0.42 (0.18)	0.31 (0.19)	0.24 (0.14)

* = significant at $p<0.05$, ** = significant at $p<0.01$

[1] = index finger, [2] = middle finger

An analysis of variance(ANOVA) was performed on all dependent measures for all tools and handles. In case of grip force exerted and normalized EMG, ANOVA showed that results for all tools were very similar except for the shovel. In Table 3, the handle effect for the shovel was significant on the grip force of left hand ($p<0.05$) and normalized EMG values of left biceps brachii ($p<0.01$), right flexor digitorum superficials ($p<0.05$), and right biceps brachii ($p<0.05$). In Table 4, the effect of handles for the increase in HR was significant in rake only ($p<0.05$). The handle effect on the lack of tactile feel was significant in rake ($p<0.05$) while the shovel had significant effect of handles on the hand slipperiness. There was no significant effect of handles on the shoveling performance.

Table 4 Results averaged over subjects (means and SD)-Increase in HR, Subjective judgment, and Shoveling performance

Tool	Handle	Increase in HR	Subjective judgment			Load shoveled (kg/min)
			Discomfort	Tactile	Slip	
Shovel	Wood	32.8(13.4)	7.3(2.4)	3.3(2.9)	6.5(3.2)*	46.64(10.40)
	Solid	32.2(14.6)	4.5(3.4)	4.4(3.5)	5.2(3.3)*	45.91(12.64)
	Hollow	30.3(12.5)	4.5(4.4)	3.1(2.5)	1.8(1.8)*	48.52(11.80)
Rake	Wood	16.1(6.2)*	4.1(3.9)	4.5(4.4)*	4.7(4.2)	
	Solid	22.8(7.2)*	4.2(3.5)	5.8(3.7)*	5.2(4.4)	
	Hollow	15.9(6.2)*	3.1(3.1)	1.3(1.6)*	2.6(3.5)	
Hoe	Wood	22.6(10.1)	4.4(3.8)	4.5(4.1)	5.2(3.9)	
	Solid	23.9(6.1)	5.0(3.4)	3.1(3.4)	3.3(3.3)	
	Hollow	22.1(6.7)	2.1(2.0)	3.2(3.7)	4.0(4.0)	

* significant at $p<0.05$

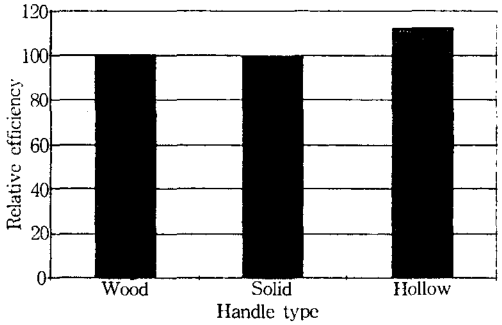

Fig. 1 Relative efficiency of shovel performance

The most effective measure for the shovel was the relative efficiency of shovel performance. In an attempt to quantify the relative efficiency of shovel performance, it was decided to use the ratio of the amount of sand shoveled per minute to the increase in heart rate per minute. This ratio represents the relative efficiency which is the same as the ratio of work load to energy consumption during work. As shown in Fig. 1, the relative efficiency of hollow fiberglass handle was increased by 12% in reference to that of wood handle. This was statistically significant ($F[2, 27]=7.33$, $p<0.01$). While the relative efficiency of solid fiberglass handle was almost the same as that of wood handle.

The grip force of palm side near the left index finger was 0.64 for the wood handle, 0.62 for the solid fiberglass handle, and 0.47 for the hollow fiberglass handle as shown in Table 3. These differences were significant at $p<0.05$. In case of palm side near the left middle finger, the grip force was 0.79 for the wood handle, 0.52 for the solid fiberglass handle, and 0.33 for the hollow fiberglass handle. These differences were also significant at $p<0.01$. These results showed that less efforts were made in gripping the shovel with the left hand using fiberglass handles compared with the wood handle. However, tool effects were not significant on the grip force of right hand ($p>0.05$).

The normalized EMG values for the flexor digitorum superficials and biceps brachii of both hands as a function of handle types were also shown in Table 3. The normalized EMG value of right biceps brachii was 0.62 for the wood handle and 0.49 for the hollow fiberglass handle, and that of left biceps brachii was 0.65 for the wood handle and 0.53 for the hollow fiberglass handle. These differences were significant at $p<0.05$. These results showed that, using the hollow fiberglass handle, fewer muscles were recruited and the work was performed more efficiently in holding the tool.

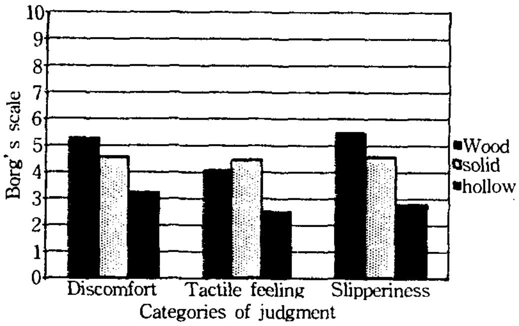

Fig. 2 Subjective judgment as a function of handle types

Fig. 2 shows the result of subjective ratings of perceived exertion averaged across three different tools. These are on a scale of 0 to 10 with a lower number being more comfortable or acceptable. Although the result was slightly different between tools, Borg's CR-10 scale of the hollow fiberglass handle was the smallest. ANOVAs given in Table 4 indicated that tool handles effects on slipperiness were statistically significant ($p<0.05$) while those effects were marginally significant (statisticians usually use $p<0.05$) for discomfort $p=0.064$, lack of tactile feel $p=0.074$. These results meant that the hollow fiberglass handle was more acceptable for comfort, lack of tactile feel, and especially decreased slipperiness.

4. Discussion

The experiment was performed to evaluate the effects of newly developed garden tools which have fiberglass handles instead of traditional wood handles on the ergonomic effectiveness, user satisfaction in terms of work performance, and subjective judgment of tactile feel and control.

The shoveling performance, the grip force and EMG of the arm muscles, and the heart rate were measured. The grip force and EMG for gripping and holding muscles were measured by using FlexComp system. After experiment, subjects were asked to perform the subjective judgment of overall perceived handle discomfort, lack of tactile feel, and handle slipperiness. The measured data were analyzed to evaluate the effects of handle type.

Overall results showed that the hollow fiberglass handle was the best in shoveling work but there was no significant difference between three different handles in raking and hoeing. In case of raking and hoeing, handle types seemed to have no effect on the work performance and the subjective judgment. They may be due to the degree of workload because the workload of hoeing and raking must be lower than that of shoveling relatively.

In shoveling, the hollow fiberglass handle was 12% more efficient than either wood handle or solid fiberglass handle. The effects of handle contour and handle diameter and the center of gravity (COG) of tools were considered to be main reasons[9]. The hollow fiberglass handle has two sides of surface with one half of the round cross section of the handle being smooth, the other half being ribbed. This ribbed surface resulted in increasing the controllability of tools because it prevented the hand from slipping during work. Contrary to what would expect, all shovels are the same weight because the shovel with fiberglass handle has a wooden core near the frog required to attach the handle to the shovel blade securely. Therefore, weight of the shovel with fiberglass handle is more concentrated near the blade. It means that the center of gravity of the shovel with fiberglass handle is located towards the blade. This deviated center of gravity may be the reason for better efficiency of shoveling with hollow fiberglass handle. This result is consistent with Kadefors et al[12]. They suggested that: 1) the mechanical output of the tool, 2) tool mass and center of gravity, 3) tool dimension, 4) tool grip, and 5) tool surface are the major factors affecting the performance of a tool grip task.

Analyses of grip force on the left hand showed a significant difference between handle types. On the other ha/nd, there was no significant difference between handle types in the right hand. The average forces required to manipulate the shovel with the wood handle were significantly higher than the average forces for the shovel with fiberglass handles. In shoveling, the role of each hand must be different. Usually, the left hand holds the shovel and load shoveled while the right hand functions as a kind of controller. In other words, the shovel weight may be maintained, for the most part, by the left hand. Also there was some concern that the grip diameter of the wood handle was larger than that of fiberglass handles. This difference of grip diameter may be another reason for less grip force of fiberglass handles. In this regard, Fellow and Freivalds showed that the tool grip force was greater for the foam grip due to the deformation of the thick foam and a loss of control feeling in the subjects[10]. Therefore, it can be certain that the wood handle grip is too large for a proper grip.

EMG analyses supported the results of grip force. Since EMG is the indirect measure for muscle forces exerted, these EMG values confirmed the results that the subjects exerted more force with the wood handle than fiberglass handles. Although all shovels are same weight, fiberglass handles are relatively lighter than the wood handle. Because of this advantage of the fiberglass as a material, the muscular efforts required to maintain or control the shovel could be decreased. This result is in agreement with Westling and Johansson's experiments[13]. According to their study, variations of grip force and grip force control are heavily influenced by the weight of the objects held, the size, and contour of the tool handle.

The hollow fiberglass handle showed better subjective acceptability in terms of overall handle comfort, lack of tactile feel, and decreased slipperiness. These results may be due to the ribbed surface of the hollow fiberglass handle. Recently, Swensen et al. have shown that there is a strong association between subjective ratings and objctive static friction measurements on dry and contaminated (wet, clay, and oil) surface for a variety of climbing and walking tasks[14]. Although the objective friction values between the hand and the handle were not available in this study, the subjective judgment may be enough to show the superiority of the hollow fiberglass handle in terms of slipperiness.

5. Conclusions

A newly developed garden tools with fiberglass handles instead of traditional wood handle were tested to evaluate quantitatively the effects of handle types of garden tools on the ergonomic effectiveness, user satisfaction, and subjctive judgment of tactile feel and control. Although overall results were well accepted for the experimental tasks, it required further specific researches to evaluate the impacts of new materials and products in detail. Furthermore, in designing and adopting new materials to hand tools, the manufacturer must consider the ergonomics and biomechanical aspects of the user-tool interface.

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