農作業研究（Japanese Journal of Farm Work Research）42（2）：91〜103, 2007

Original Paper

Ergonomic Study on the Process of Mastering Reversible Plow Operation using Ride-on Tractor

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乗用型トラクタによるリバーシブルプラウ作業の習熟過程に関する人間工学的研究

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1. Introduction

1) Background

Tractors are considered the most important power sources in modern agriculture. Compared to the walking type, ride-on tractors are extremely convenient and effective. However, they are also more powerful and complex. Thus they can be dangerous machines unless users understand and operate them properly. Many studies have reported that tractor accidents are the leading cause of agricultural fatalities in many countries and that operator error is one of the main reasons for the accidents (Becker *et al.,* 1992 ; Denenberg, 1976 ; Kroemer *et al.,* 1997 ; Pickett *et al.,* 1999 ; Snedecor, 1956)

Despite the enormous technical development of agricultural machinery, ergonomic or human factor studies related to the operation of the machineries appear to be very limited. Therefore, more attention and study of operation performance, task accuracy and work physiology are necessary to find effective ways to improve operator training and work safety education.

In order to provide basic data about operator performances and the mastering process of tractor operations, the authors have been conducting ergonomic research on various tractor operations. The previous papers reported on the process of mastering the operation of walking-type rotary tillage (Syuaib *et al.,* 2002) and rotary tillage by ride-on tractor and driving course (Syuaib *et al.,* 2003).

There are many small fields subdivision in Japan and Indonesia. In the small field, reversible moldboard-plow is an effective implement because consecutive plowing method can be adopted. By above-mentioned perspective, the process of mastering on the operation of reversible moldboard-plow using ride-on tractor was studied in the present paper.

2) Research Objectives

This study was conducted with the main objectives to provide basic data about tractor op-

平成 17 年 11 月 17 日受付
平成 19 年 5 月 2 日受理
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erator performance and physiological strain, and to find the important factors in the mastering process of the tractor operations, particularly reversible moldboard-plow, from an ergonomics perspective. Furthermore, this study seems to be ultimately useful for farm work improvement, because the difficult work motion can be pursued.

The objectives of this experiment were follows :

(1) To investigate the difference of physiological strain and technical performance between beginners and skillful operators on the reversible plow operation.
(2) To determine the significance of interpersonal variation among the beginners.
(3) To analyze the skill-improvement patterns of beginners in accordance to the length of practical tractor experience.
(4) To analyze the effect of car-driving experience of the beginners on the process of mastering tractor operation.
(5) To analyze the learning period required for beginners through learning curves modeling.

2. Materials and Method

1) Place and Time of Experiment

Field experiments were carried out at the experimental farm of Ibaraki University from May to October 2001 and May to July 2002.

2) Materials and Instruments

The main materials and instruments consisted of :

(1) Ride-on tractor : 14.7 kW (20 PS) with one set (two bodies) of single reversible moldboard-plow (share width 35 cm) implement, max.length 4.48 m and max.width 1.40 m including the implement. The plow rotation was activated by hydraulic pump that was installed on the PTO shaft, since the tractor had not been equipped with a hydraulic outlet coupler.
(2) Portable Heart Rate Monitor
(3) Portable Breath Analyzer
(4) Digital Video Camcorder
(5) Video Cassette Editor and Video Timer

3) Subjects

Empirical data were collected from twelve healthy subjects, who voluntarily participated in designated field experiments. Beginners were defined as the subjects who had no previous experience with tractor operation. Skillful operators were the subjects who had regular jobs as professional tractor operators. Based on their ability to drive an automobile, beginners were classified as either : (1) “Driver’s License Beginners” (*DL-beginners*) who were accustomed to drive an automobile, and (2) “Non Driver’s License Beginners” (*NDL-beginners*) who didn’t drive an automobile. Two of the subjects were skillful operators who worked at the university experimental farm. The other ten subjects were beginners who were recruited from among university students. There were 5 NDL-beginners and 5 DL-beginners. All the subjects were male and their physical characteristics are given in Table 1. The automobile driving experiences of DL-beginners were about 3–5 years.

4) Research Method

The tractor used for the experiments was equipped with a frame for a video camera mounted over a non-canopy cabin. The camera recorded all hand and foot task motions of the driver during the observations. The video editor and video timer were used to analyze the recorded videotape for the motion and time study (Barnes, 1980).

Plowing capacity was 36 cm in width and 15～20 cm in depth at 1.8 km/h tractor speed. One observation consisted of 8 plowing rows (20 m long each) and 8 turning operations. The experimental field layout is given in Figure 1. Beginners were observed for 10 times and skillful operators were observed for 7 times. The effective operation time of DL-beginners and NDL-beginners for one observation was 11.4 and 12.0

Table 1 Characteristics of the subjects

Skill Category	Number of Subjects	Age Range (yrs.)	Weight Range (kg)	Height Range (cm)
NDL- beginner	5	19～22	56～97	166～177
DL-beginner	5	21～24	56～78	167～180
Skillful Operator	2	38～39	56～61	170～175

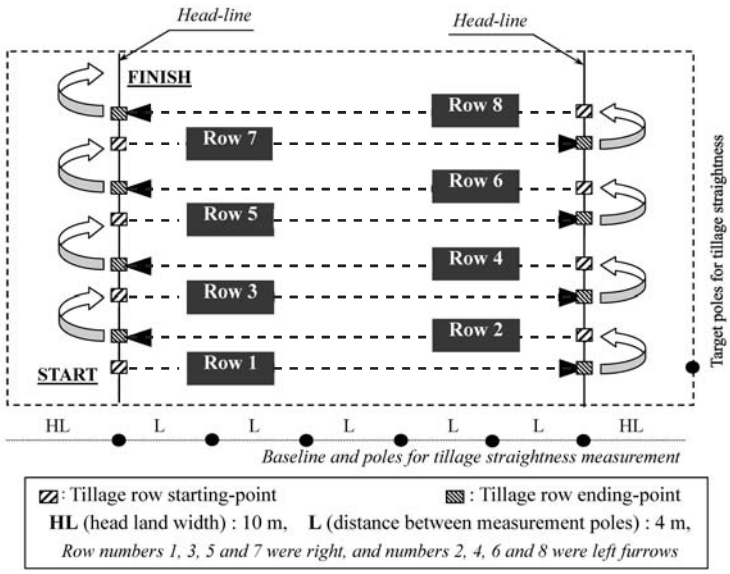

Fig. 1 Experimental field layout

minutes on the average, respectively.

The subjects were clearly instructed to follow the designated experimental route and to strictly follow the same operating procedures. The basic operation of tractor and the main attention of plowing method were explained to the beginners before the real experiment. Those main matters are as follows.

(1) The function of clutch, brake and various control levers.
(2) The appropriate operation method of steering wheel.
(3) To step on the clutch pedal at first, and then brake pedal when the tractor is stopped.
(4) To take the timing of plow up and down by attention to the head land line (headline as an abbreviation) which is a standard.
(5) To utilize the target pole which was stood at the edge of head land to travel straight in case of first row.
(6) The timing of steering wheel operation and the positioning of tractor in turning.
(7) The procedure of gear change and plow inversion operation in turning.
(8) To be traveled straight the tractor for the next row after turning.

The subjects were also informed about the measurement parameters, such as : tillage straightness, turn tasking time, tillage starting and ending errors. The subjects experienced the operations of various levers and pedals in the condition that the tractor stopped, and then practiced the plowing of both ways (two rows) before the real experiment. As the occasion de-

mands for the real experiment period, the beginners were given some instruction on the tractor positioning, the timing of lever operation, etc.

The heart rate and oxygen consumption of the subjects were continuously recorded as a physiological strain indicator. The measurement values of rest periods before and after the experimental observations were used as a baseline for the physiological strain measures.

Specifically, the analysis items of this research are :

(1) Physiological strain analysis of work (Sanders *et al.,* 1993 ; Syuaib *et al.,* 2002 ; Syuaib *et al.,* 2003). This item includes analyses of heart rate (HR) and oxygen consumption (VO_2).

(2) Technical performance analysis (Syuaib *et al.,* 2002 ; Syuaib *et al.,* 2003). This item includes the technical aspects of tractor operation, such as tillage straightness deviation, tasking error (tillage starting and ending-point errors) and time. The distances of each tillage row from the measurement baseline were measured at six poles points (see Figure 1), and the standard deviation was calculated as the straightness deviation of the each tillage row. Since one experiment consisted of 8 tillage rows, the tillage straightness deviation was an average of eight data. Tillage starting or ending-point error was calculated as an average of absolute error from the head-line of the starting-point or ending-point of a tillage row

(3) Statistical analysis (Denenberg, 1976 ; Snedecor, 1956). The analysis of variance and *T-test* analyses were mainly used to examine the significance of individual variability and the skill improvement process among the subjects.

3. Results and Discussion

1) Physiological Strain Analysis

As it was previously mentioned, the physiological strain was analysed in terms of Increase Ratio of Heart Rate (IRHR) and Relative Metabolic Rate (RMR). IRHR was calculated in the following equation.

$$IRHR = HRw / HRr$$

Where HRw is the heart rate level during activity (work) ; HRr is the heart rate level in resting condition.

The measurement results of physiological strain are shown in Figures 2〜5. The graphs reveal that almost no significant difference in physiological strain levels between the beginners and skillful operators was found. These results differ from the results of a previous study on the walking-type tractor operation (Syuaib *et al.,* 2002). Its cause is guessed with the difference of operating method and quality like the following of both tractors. ① Ride-on tractor is operated by sitting in the driver seat, whereas walking-type tractor is operated by walking behind the tractor. Thus, the physical workload in the walking-type tractor operation is higher. ② In case of walking-type tractor, it is essential for the operator to synchronize the walking pace and steps with the tractor speed as well as to control the tractor's direction. So, for the beginners who have no prior experience, the mental and physical efforts in walking-type tractor operation are obviously higher than those of skillful operators.

In comparing the physiological strains be-

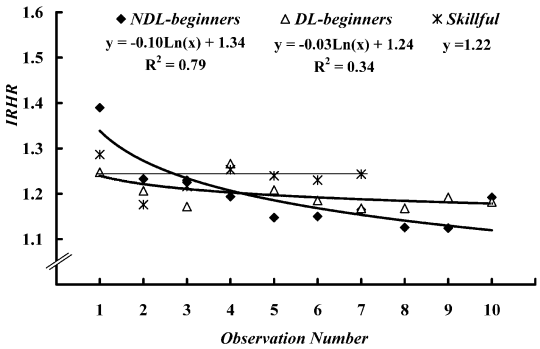

Fig. 2　Increase Ratio of Heart Rate (IRHR) in the straight tillage tasks

tween straight tillage and turning tasks in general, the results showed that the IRHR and RMR of the turning task tended to be slightly higher than those of the straight tillage task, both for beginners and skillful operators. These results mean that the turning task was slightly more strenuous than the straight tillage task.

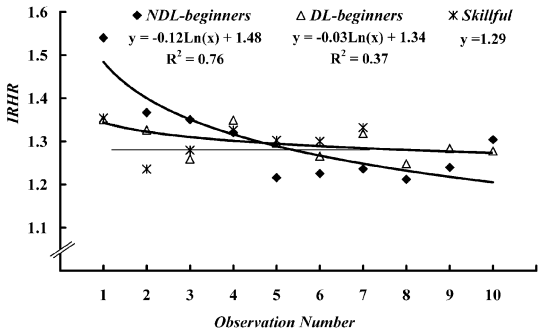

Fig. 3 IRHR in the turning tasks

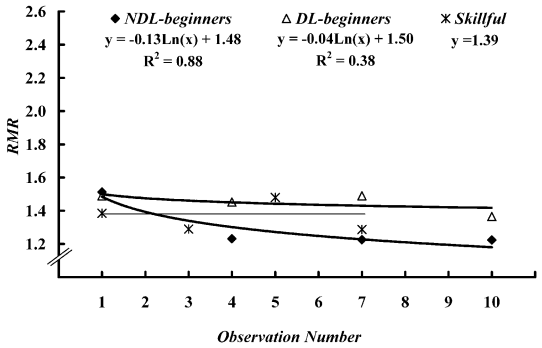

Fig. 4 Relative Metabolic Rate (RMR) in the straight tillage tasks

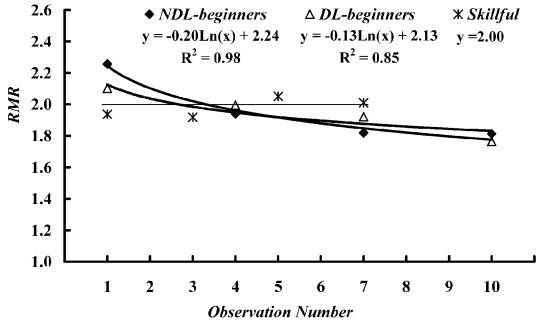

Fig. 5 RMR in the turning tasks

In the case of straight tillage tasks, the comparisons of IRHR and RMR among the subject groups are shown in Figures 2 and 4, respectively. The IRHR of NDL-beginners was relatively high at the beginning of the observations (i.e. observations #1 to #3) as compared to the other subject groups, whereas almost no difference in RMR was found among them. The same results were also recognized in the case of turning tasks (Figures 3 and 5).

In general, the RMR reflects only the physical workload, and the IRHR is affected by both physical workload and mental stress. The above results, therefore, revealed mental stress (i.e. nervousness) was especially noticeable in the NDL-beginners and it's fairly certain that it adversely affected their performance. Since the NDL-beginners had no previous experience with either car-driving or plowing operation, the mental stress might have been caused by the operation tasks or the experimental conditioning. At any rate the higher the subject's skill and experience was, the lower the mental stress appeared to be.

Some other interesting results were found in the regression model of the IRHR graphs as shown in Figures 2 and 3 above. The IRHR of NDL-beginners in obs.#1～3 was higher than those of DL-beginners and skillful operators. However, after obs.#4 the IRHR levels of the NDL-beginners became the lowest, while the skillful operators showed the highest ones. These phenomena suggested that the physiological measures were affected more by the individual characteristics of the subjects (i.e. age, daily physical condition, psycho-physiological characteristics, etc.). In addition, the levels of physiological strain (i.e. IRHR and RMR) indicated that the workload level of this ride-on plowing operation could be categorized as light. Therefore, it is guessed that the internal or individual factors of the subjects, rather than the actual workload itself, greatly affected the measures of physiological strain.

2) Technical Performance Analysis

As it was previously mentioned, the technical performance was analysed in terms of tillage straightness deviation, tillage starting-point and ending-point errors, and turn tasking time. The results of technical performance analysis are shown in Figures 6 to 10.

Figure 6 shows the average of tillage straightness deviations of each subject category (i.e. NDL-beginners, DL-beginners and skillful operators). The tillage straightness deviation of NDL-beginners was considerably larger than that of DL-beginners. Therefore, the graphs clearly show that there was a significant difference in tillage straightness performance between NDL and DL beginners.

The performance of DL-beginners was somewhat better and stabler than that of the NDL-beginners. It is also noticed that the regression pattern of the learning curve differs between the two categories of beginner. In case of NDL-beginners, the tillage straightness deviation greatly decreased from first observation (obs. #1) to third observation (obs.#3), after which it gradually decreased until obs.#10. On the other hand, the tillage straightness deviation of DL-beginners very gradually decreased from obs. #1 to obs.#9. These findings mean that the DL-beginners had the advantage of recognition and judgment over the NDL-beginners when operating the tractor on a straight path, since they were accustomed to driving an automobile. In short, this proved that the recognition and judgement of DL-beginners for tractor operation were higher than those of NDL-beginners at the test starting time. Compared to the skillful operators, the tillage straightness deviation of DL-beginners was slightly higher, however, T-test results revealed no significant difference between them.

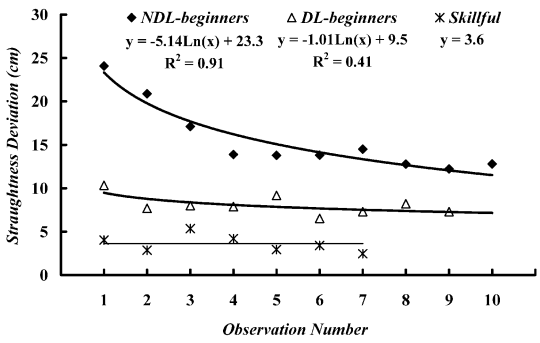

Fig. 6　Tillage Straightness Deviations

Regarding the graphic equations of tillage straightness deviation shown in Figure 6, the intersection of the beginner and skillful operator lines was calculated on the assumption that the graphic patterns hardly change in its extension after the numbers of practical observations. From the results, NDL-beginners were expected to reach the first tillage straightness level of DL-beginners within 15 practical operations (about equal to 3 hours of effective practical time : e.p.t.), whereas another 344 practical operations (65 hours e.p.t.) were suggested as the minimum times required for DL-beginners to reach the tillage straightness level of a skillful operator.

Figures 7 and 8 show the tillage starting-point and ending-point errors, respectively. Generally, the errors of the beginners were extremely high in the beginning of the observations, and then gradually approached the level of skillful operator. However, the graphs reveal that the improvement rates of the DL-beginners were much faster than those of the NDL-beginners. Regarding the learning curves equation, DL-beginners were expected to reach the same level as skillful operators within 13 and 12 practical operations for starting-point and ending-point errors, respectively. In the case of NDL-beginners, these values were respectively, about 213 and 122 practical operations. From these numerical value, it is inferred that the timing of the tillage start operation for the NDL-beginner has been made to be weak point.

The time and motion analysis in this study was mainly focused on the turning task, since complex and strenuous task sequences were more necessary in turning than in the straight

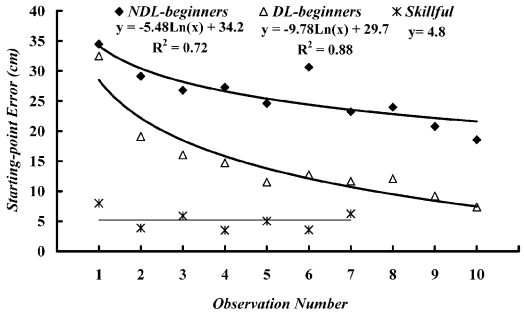

Fig. 7 Tillage starting-point errors

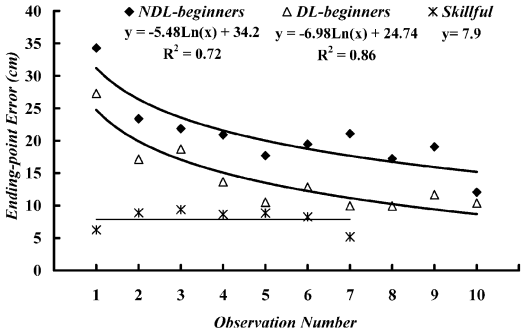

Fig. 8 Tillage ending-point errors

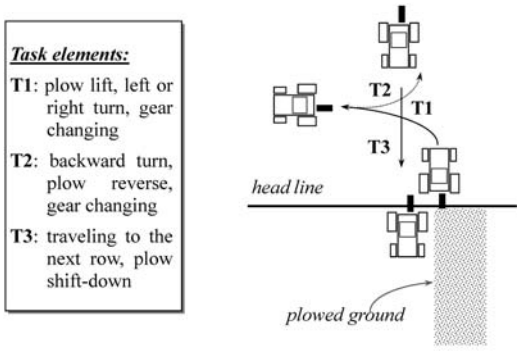

Fig. 9 Turn tasking procedures

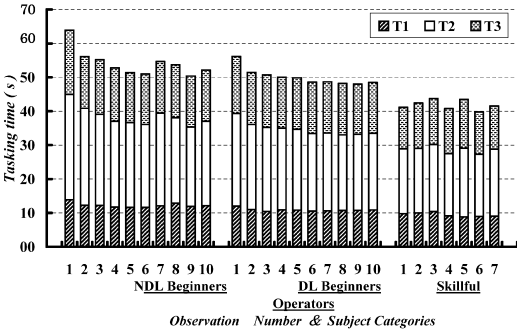

Fig. 10 Turn tasking times

tillage. The turning task was divided into three major groups of operation elements, "T1", "T2" and "T3" (see Figure 9). Figure 10 shows the results of the analysis of motion time for each subject category.

Compared to the beginners, the turn-tasking time of the skillful operators was significantly shorter. Total turning time (T1+T2+T3) of skillful operators was about 40 to 45 seconds, whereas the time of the beginners were considerably high in the first operation experience but tended to improve during the practical training. The average turning time of NDL and DL beginners were, respectively, about 64 and 55 seconds in the first observation (obs.#1), and then gradually decreased to 53 and 49 seconds respectively in obs.#10. The graphs clearly show that the tasking time of DL-beginners improved with more consistency and smoothness than that of the NDL-beginners.

Regarding the graphs of turn tasking time shown in Figure 10, the main difference in turn-time pattern was found in the T2 element. As illustrated above in Figure 9, the T2 element mainly consisted of a back turn (making a space for directing the tractor to the next row position) and gear changing tasks (back/forward gear and plow reversing). The data revealed that the turning area made by the beginner was somewhat bigger than that of the skillful operators. The beginners need a turning space of about 8.3 to 10.3 m (the distance between the farthest point of the tractor to the field headline), whereas the skillful operators need not more than 7.5 m turning space. In addition, the beginners also took a relatively longer time to change the gear levers' position, and often made also some operation mistakes. Therefore, the "T2" element time of the beginners was relatively longer compared to that of the skillful operators. Since the beginners tend to use rel-

atively wide turning area, it's really important to note here that special check and attention to the work safety around the turning area is necessary before a beginner can do a plowing operation, especially in a relatively small field.

Figures 11 and 12 show the individual values of tillage straightness deviation, as one of the technical performance parameters, for DL and NDL beginners respectively. A comparison of the technical performance between the two groups of beginners showed that the interpersonal variation within the NDL group was generally much higher than that of the DL group. Namely, it's clearly see that the data of the NDL-beginners widely varied, whereas the data of DL-beginners was relatively stable. This tendency was also recognized in the other parameters. In addition, within 10 practical observations the tasking time and error levels of the

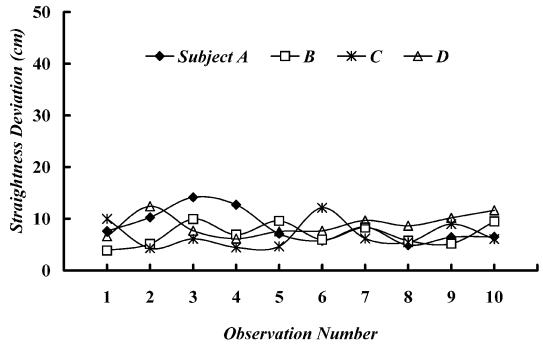

Fig. 11　Individual values of tillage straightness deviation of DL-beginners

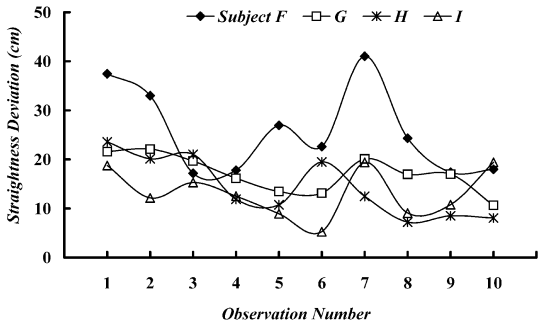

Fig. 12　Individual values of tillage straightness deviation of NDL-beginners

NDL-beginners were usually higher than those of the DL-beginners. These facts suggest that the ability to drive an automobile was cognitively advantageous to the learning process of the tractor operation.

Among the technical performance parameters that were analysed in this study, keeping the tillage straight was recognized as the most difficult task, even for the subjects who were accustomed to driving an automobile. The main reason is related to the nature of plowing. That is, in the plowing operation wheels on one side of the tractor must run in the furrow that appeared on the previously plowed path, while the other tractor's wheels remain on the field-level surface. In other words, the tractor is operated in a slant position. This affects the balance control of the operator, especially a beginner who is not accustomed to such operating situation. In addition, once the operator makes a crooked tillage path, it is difficult to straighten it on the next row, since the tractor's wheels are trapped in the furrow. In many cases, the beginners made a relatively straight track in the first row, where was no furrow yet on the field. But subsequent rows became less straightness.

3) Statistical T-test Analysis

Statistical multiple T-test was utilized to analyse the improvements which the beginners made within a certain number of practical observations. Two T-tests were carried out as follows :

(1) T-test between the observation numbers (obs.#1 to #10) for each analysed parameter within each beginner's group (NDL or DL beginners). The results are given in Tables 2 and 3.

(2) T-test between the subjects' groups (NDL-beginner, DL-beginner and Skillful) for each analysed parameter. The results are given in Tables 4 and 5.

Tables 2 and 3 respectively show the results of T-test analyses within the beginners' groups,

Table 2 The results of T-test analyses of NDL-beginners (5 persons)

Analysed Parameter	Nominators*						
	Obs.#1	#2	#3	#4	#5	#6	#7
Tillage Straightness Deviation	#5, 9	N	N	N	N	N	N
Tillage Starting-Point Error	N	N	N	N	N	N	N
Tillage Ending-Point Error	#2〜10	#10	#10	#10	N	N	N
Turn Tasking Time	#2, #4〜10	N	N	N	N	N	N
IRHR of Tillage Tasking	#5〜10	N	N	N	N	N	N
IRHR of Turn Tasking	#5〜10	#5〜8	N	N	N	N	N
RMR of Tillage Tasking**	N	—	—	N	—	—	N
RMR of Turn Tasking**	#7, 10	—	—	N	—	—	N

Note : Numbers in the cells are the observation numbers that show significance with the nominator ($p<0.05$). N : no significance.
*The observation number used as the base in the T-test.
**RMR data were collected only at the 1st, 4th, 7th and 10th observations.

Table 3 The results of T-test analyses of DL-beginners (5 persons)

Analysed Parameter	Nominators*						
	Obs.#1	#2	#3	#4	#5	#6	#7
Tillage Straightness Deviation	N	N	N	N	N	N	N
Tillage Starting-Point Error	#2〜10	#5, 7, 9, 10	#10	#10	#10	N	N
Tillage Ending-Point Error	#2〜10	#5, 7〜10	N	N	N	N	N
Turn Tasking Time	#3〜10	N	N	N	N	N	N
IRHR of Tillage Tasking	N	N	N	N	N	N	N
IRHR of Turn Tasking	N	N	N	N	N	N	N
RMR of Tillage Tasking**	N	—	—	N	—	—	N
RMR of Turn Tasking**	N	—	—	N	—	—	N

Note : Numbers in the cells are the observation numbers that show significance with the nominator ($p<0.05$). N : no significance.
*The observation number used as the base in the T-test.
**RMR data were collected only at the 1st, 4th, 7th and 10th observations.

NDL and DL. In case of tillage straightness deviation in Table 2, obs.#1 was statistically significant with obs.#5 and obs.#9. It is also shown that most of the technical errors in obs.#1 showed significant difference with the other subsequent observations, for both the NDL and DL beginners. These findings revealed that the first operation experience was technically hard for the beginners. Significant improvement of technical performance mainly began within the period of obs.#4〜5.

In case of physiological strain parameters for NDL-beginners, obs.#1 of all parameters except the RMR of tillage tasking showed significant difference with most of the subsequent observations. This result means that the physiological strain of obs.#1 was markedly high. On the other hand, for the DL-beginners, there was no significant change in either IRHR or RMR.

Table 4 shows the results of T-test analysis between the beginners and the skillful operators. In the case of physiological strain parameters, no significant differences of IRHR and RMR were indicated in any of the observations, except the IRHR on the turn tasking of NDL-beginners in obs.#1. In case of the technical parameters, the results of Table 4 clearly show that the technical errors of the NDL-beginners were significantly higher than those of skillful operators. On the other hand for the DL-beginners, no significant difference of technical parameters with the skillful operator was found after the obs.#5. In addition, the T-test results showed “no significant difference” in the tillage straightness deviation between the DL-beginners and skillful operators in all the observations.

Table 5 shows the results of T-test analysis between the NDL and DL beginners. Some significant results in the parameters of tillage straightness deviation, starting-point error and turn tasking time can be noted. In case of the

Table 4　The T-test results of Beginners vs Skillful operators (by observation number)

Analysed Parameter	Observation Number						
	1	2	3	4	5	6	7
Tillage Straightness Deviation	a	a	a	a	a	N	N
Tillage Starting-Point Error	b	b	a	b	b	a	a
Tillage Ending-Point Error	b	b	a	a	a	N	N
Turn Tasking Time	b	b	b	b	a	a	a
IRHR of Tillage Tasking	N	N	N	N	N	N	N
IRHR of Turn Tasking	a	N	N	N	N	N	N
RMR of Tillage Tasking	N	—	—	N	—	—	N
RMR of Turn Tasking	N	—	—	N	—	—	N

Note :
a : Only the NDL beginner was statistically significant ($p < 0.05$).
b : All beginners (DL and NDL) were statistically significant ($p < 0.05$).

Table 5　The results of NDL vs DL-beginners T-test (by observation number)

Analysed Parameter	Observation Number									
	1	2	3	4	5	6	7	8	9	10
Tillage Straightness Deviation	*	*	*	*	N	N	N	N	N	N
Tillage Starting-Point Error	N	N	N	N	**	**	*	*	N	*
Tillage Ending-Point Error	N	N	N	N	N	N	N	N	N	N
Turn Tasking Time	*	*	*	N	N	N	N	N	N	N
IRHR of Tillage Tasking	N	N	N	N	N	N	N	N	N	N
IRHR of Turn Tasking	N	N	N	N	N	N	N	N	N	N
RMR of Tillage Tasking	N	—	—	N	—	—	N	—	—	N
RMR of Turn Tasking	N	—	—	N	—	—	N	—	—	N

Note * : $p < 0.05$, ** : $P < 0.01$, N : no significance.

tillage straightness deviation, there was significant difference between NDL-beginners and DL-beginners within obs.#1～4, but not for the obs.#5～10. This fact means that the significant improvement of tillage straightness capability of the NDL-beginners occurred in obs.#1～4, and the tillage straightness deviation of NDL-beginners approached that of DL-beginners. With the same thought, the turn tasking time of the NDL-beginners had been improving in obs.#1～3.

Table 5 shows that the tillage starting-point operation of DL-beginners improved more progressively and their technical errors were significantly less than that of the NDL-beginners after the obs.#5 (refer also Fig. 7). This result matched with the result given in Table 4, which proved that no significant difference in tillage starting-point error appeared between skillful operators and DL-beginners after obs.#5, but still appeared for NDL-beginners. The tillage ending-point error and physiological strain parameters in Table 5 showed no significant difference between DL and NDL beginners in all observations.

4. Conclusions

This research has provided basic ergonomic data and analysis related to physiological strain and technical performance of skillful operators and NDL and DL beginners in the operation of a ride-on reversible plow. In addition, the mastering process and the task difficulties in the plow operation were successfully identified.

Tillage straightness was proved to be the most difficult task for the beginners to master. The typical nature of the operation procedures, which require putting one side of the tractor's wheel in a furrow that makes the tractor position tilted, might be the main cause.

Through comparative analyses among the subject groups, the different process to master the tractor operation between the beginners who had a car-driving background (DL-beginners) and those who did not (NDL-beginners) could be clearly understood. In this regard, the significant advantage of automobile driving ability to the process of mastering tractor operation was clearly proved.

Through the analyses of physiological strain levels, it has been proven that there is no significant difference of physical burden between beginners and skillful operators. However, high physiological strain was recognized at the beginning of practical experience of the NDL-

beginners.

The necessary instructional steps and adequate learning quantities for the beginners were found. Compared to the DL-beginner's group, the improvement process of NDL-beginners individually varied and a high physiological strain often occurred in the beginning of the learning period. From the results of analyses on technical performance, an effective working (learning) time of about 65 and 68 hours is recommended for DL and NDL beginners respectively to reach the necessary level of performance.

The high interpersonal variation in the analyzed parameters among the beginners, NDL-beginners especially, indicates differences in motion abilities and perceptions among them to perform the operation tasks. This suggests that the instructor must consider the individual differences among the beginners to guide and instruct them, especially until they reach psychological stability

In the following, the various measurement results of the physiological strain and technical performance parameters are synthetically considered. The physiological strain of NDL-beginner as well as DL-beginner became a level, which was equal to skillful operator within the fifth observation. As a result of examining mastering process of various technical performances, it was proven that the skill improvement of tillage straightness was especially slow. From above-mentioned various results, the time until the technical performance of the tillage start operation reaches the skillful operator's level is made to be a first step (DL-beginners : about 3 hours, NDL-beginners : about 43 hours) of the mastering process, and the time after it may be divided as the second step. In short, the beginner surely acquires the basic operation of the tractor in the first step, and it seems to become a condition that stabilized in the mentality. Therefore depending on the situation, the practice of the second step is considered that it may be made to be the self-training.

Acknowledgements

The authors are grateful to Mr. Masanori IKEDA (Experimental Farm of Ibaraki Univ.), Mr. Masayuki TAKAHASHI and the colleagues at the Laboratory of Bioproduction Systems Engineering, Ibaraki University for their helpful assistance, opinions and support during the research.

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Abstract

This research was mainly conducted to obtain basic ergonomic data about tractor operator performance and to analyze the mastering process of tractor operation, especially reversible moldboard-plowing using a ride-on tractor. This paper mainly deals with the analysis of learning curve patterns of beginners to assess the necessary expertise level through a comparison with skillful operators. Comparative analyses between beginners who do and do not have automobile-driving experience are also discussed. Suggestions for the minimum account of practice and instructional attentions are also given.

It was proven that the automobile-driving capability of beginners was cognitively advantageous for the learning tractor operation. Compared to the skillful operators, almost, no significant difference in physiological burden was recognized in the beginners, except at the beginning of practical experience of the non-drivers-licensed beginners. The tillage straightness was clearly the most difficult task to be mastered. In this regard, a minimum working (learning) time of about 64 and 67 hours is recommended for DL and NDL beginners, respectively, to reach the necessary level of performance. From the various results, the mastering process of reversible plow tillage may be divided into the first and second steps. Depending on the situation, the practice of second step (DL-beginners : after 3 hours, NDL-beginners : after 43 hours) is considered that it may be made to be the self-training.

Key Words

ride-on tractor, reversible plow, physiological strain, technical performance, beginner, learning-curve

要　旨

本研究は初心者と熟練者のトラクタ操作技能に関する基礎的データを求め，初心者教育や作業安全に役立てる目的で始めたものである．本論文では，乗用型トラクタによるプラウ耕うん作業における運転者の生理的負担，作業精度および動作時間の測定データを用いて，トラクタ操作の習熟過程を人間工学的視点で考察した．なお，本報では被験者を熟練者，普通自動車免許所有の初心者（免許所有初心者），普通自動車免許無しの初心者（無免許初心者）に 3 区分し比較・検討した．

プラウ耕うんのトラクタ操作において，生理的負担（心拍数増加率，RMR）は初心者と熟練者間で総体的な差異が認められなかった．ただし，無免許初心者の場合，実験回数 3 回まで心拍数増加率が他の被験者に比べ明らかに高い値を示した．

作業誤差（直進性偏差，耕うん開始・終了位置誤差）は，無免許初心者が最も大きく次いで免許所有初心者，熟練者の順であり，これらの三者間に大きな差異が認められた．初心者の場合，普通自動車の運転経験が耕うん作業のトラクタ操作に役立っていることが検証された．また，前記の 3 種類の作業誤差値と作業回数の関係より，プラウ

耕うん作業においてトラクタの直進性を向上させることが初心者にとって最も困難であることが分かった．初心者が直進性偏差で熟練者レベルに達するには 65〜68 時間を要すると推察される．また，プラウ耕うん作業の生理的負担と作業誤差の諸測定結果より，初心者の習熟過程は 2 段階に分けうると判断された．そして場合によっては，第 2 段階（免許所有初心者 : 約 3 時間以降，無免許初心者 : 約 43 時間以降）の練習は，自習でもよいと考察される．

トラクタの旋回所要時間では，3 区分の被験者間で前記の作業誤差と同様に明確な相違が認められた．免許無しの初心者が当然最も長い旋回時間であるが，その主な原因はギヤーチェンジやプラウ反転操作を含む後退時にあった．

キーワード

乗用型トラクタ，リバーシブルプラウ，生理的負担，技能，初心者，学習曲線