Timeline Effects of Vocal Instructions from Computer Programs on Agricultural Technical Teaching

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***Abstract*—Recently, real agricultural workers on general outer farmlands have had serious difficulties in lecturing their traditional manual skills to young, inexperienced workers. We have researched traditional, manual daily tasks of agricultural workers, and developed promising application systems. In terms of passing on traditional skills, we have been focused on wearable sensing systems to send useful vocal instructions (VIs) to improve the actions and postures of inexperienced workers synchronously. Time-line data of physical acceleration and angular velocity were recorded with directly attached sensors on the lower arms, chest and waist of users and the hoe that they hold. Furthermore, these data were sent to original programs installed on a laptop computer in a knapsack on the back of the user. And, while those data were logged by programs, calculated by various statistical and human dynamics methods in aforementioned programs, VIs recorded originally previously by us were also sent. To improve and reform the agricultural techniques of inexperienced workers, and to maintain the safety of users, VIs is provided through an earphone. The thresholds of various analyses were based on accumulated and analyzed time-series of data obtained in preliminary trials. We also obtained visual data, and executed optical flow analysis by combining the techniques of statistics using programs based on Open CV. By reviewing them totally, we confirmed the validity and usefulness of our system, which can assist inexperienced users to make their motions close to the experienced worker. However, the same time, the unselfconscious motions of experienced workers are totally more effective and sophisticated. From these results and work products, we believe the precise measuring and judging those motions will heighten workers skills and their safety level. And those will be significant.**

***Index Terms*—wearable sensing system, real-time vocal instruction, detecting crisis, tradition of skill, optical flow analysis.**

I. Introduction

There have been many reports on the present critical shortage of methodologies concerning "skill-tradition" from "mature" (experienced) agricultural workers to "immature" (inexperienced) workers. Various skills and methods traditionally exist [1]-[3].

However, the passing on of knowledge has been supported by the integrated systems aforementioned in Abstract. The field of agricultural informatics in itself is still growing and advancing.

Real-time wearable sensing systems (WSs), and instruction systems have been utilized in various fields, not to mention including agricultural informatics [4]-[7].

There has been no research on "concrete real user instructions" for improving physical tasks of agricultural work, especially in terms of instructions given to inexperienced workers. Our research supports inexperienced workers employing electronic technologies, human dynamics and statistical methods by providing the workers with original, real-time feedback. (see Fig. 1).

II. Methodology

A. System

We reviewed past industrial goods, patents, and academic papers [8], and discussed our findings with researchers in the field of agricultural informatics, workers, and farmland managers.

It became evident that past studies and policies have insufficiently addressed such problems related to difficulties of skill tradition. Essentially following results obtained by Kawakura [3], we designed system constructs to measure and analyze acceleration and angular velocity employing general human dynamics and statistics. Additionally, we provide instructions on our data processing to users and managers.

After outlining our system, we selected existing, promising techniques and modules, designed each part of our system (e.g., mechanical and computer systems and processing procedures), and tested the system to estimate

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its utility and suitability. We then created WSs (see Figs. 2–5), including three TSND121 multi-sensors (ATR Promotions Inc.).

We obtained time series of acceleration and angular velocity data, which we analyzed using original programs written in Visual Basic 2010. Additionally, we obtained visual data for the subject in a static position (from a distance of 3.5 meters using a common (nonspecific) digital video camera (CANON 410f ixy, 20 fps) on a solid frame, considering the later system's wide spread and circulation in public. We then analyzed the data using original programs written in Visual C++ 2010 to output data as AVI-styled file, and many general Open CV 2.3 libraries and classes [9]-[11].

Figure 1. Outline of measurements and analysis

Figure 2. Original belt and vest WSs including microcomputers and various devices and commercially available sensing modules

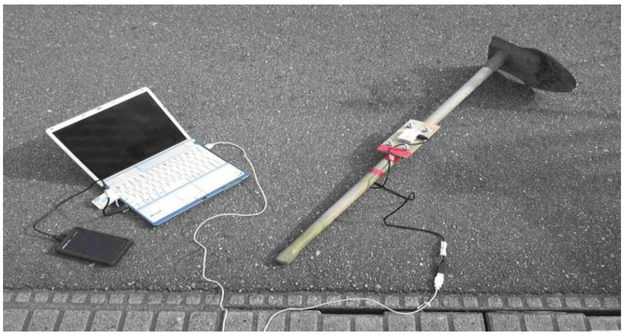

Figure 3. Hoe connected to sensors and laptop PC; the system is stored in a knapsack

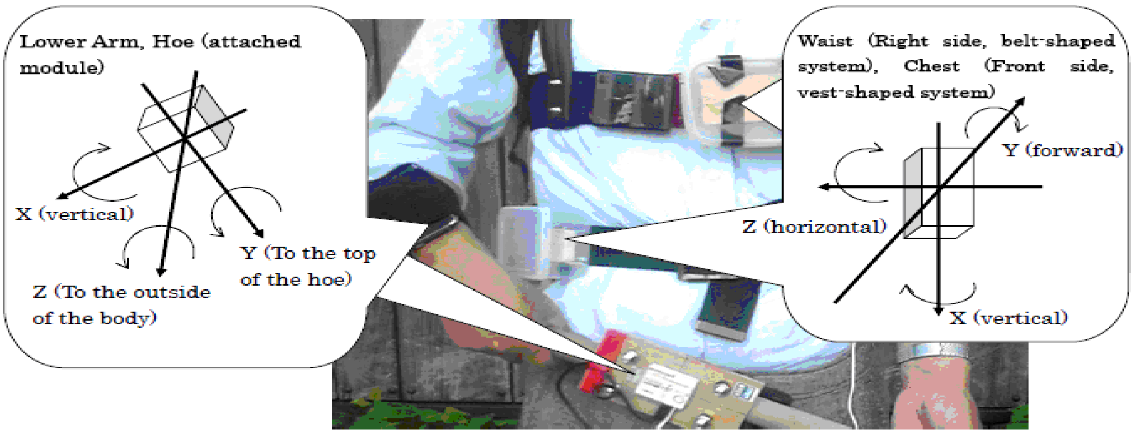

Figure 4. Coordinate axes of WSs

Figure 5. Subjects equipped with WSs listening to VIs through an earpiece

B. Subject

We selected 12 inexperienced male subjects (see Table I) and one experienced subject (having almost the average body size of a Japanese (baby-boomer) experienced farmer). The experienced subject had five years' experience, which is recognized as generally sufficient by many farmland managers.

The subjects did not have remarkable mental or physical characteristics in terms of having serious disease, remarkable stature or weight, remarkable habits, or specific careers.

According to such characteristics of subjects, we set the average values of age, stature, and weight as evenly as possible, but the standard deviations of inexperienced Group A for each item was rather high.

TABLE I. BASIC INFORMATION OF SUBJECTS

Index	Cultivating (digging) with a hoe			Other tasks	
	Immature, inexperienced Group A (N=6)	Immature, inexperienced Group B (N=6)	Mature, experienced (N = 1, only for data sampling)	Immature, inexperienced (N=1)	Mature, experienced (N=1)
Experience (year)	None	None	5	None	5
Age (year)	22–38 (Average (Ave) 27.2, S.D. 5.87)	23–26 (Ave 24.2, S.D. 1.07)	63	34	63
Stature (cm)	167–180 (Ave 174, S.D. 4.07)	170–180 (Ave175, S.D. 3.34)	170	172	170
Weight (kg)	43–75 (Ave 63, S.D. 9.9)	58–78 (Ave 67, S.D. 7.9)	66	63	66
Dominant hand	Right (all subjects)	Right (all subjects)	Right	Right	Right
Past serious physical disorder	None	None	Acute low back pain	None	Acute low back pain
Fitness habits	None or tennis or badminton (once or twice per week)		Walking	Walking, cycling	Walking

C. Selection of Tasks

We categorized common, useful, and traditional agricultural tasks after listening to real farmers (see Table II).

We selected (1) work in a sitting position and (2) cultivating (digging up soil) with a hoe in a semi-crouching position because these movements are relatively popular, repetitive and involve rather large full-body motion.

Fig. 6 is a timeline for each trial. Each trial of (1) lasted 1 minute and each trial of (2) comprised 30 swings. Furthermore, (2) was carried out with and without VIs (see Fig. 7).

Each set of trials was conducted successively on the same day, included waiting intervals of a few minutes.

We observed the subjects' daily tasks and conducted various interviews preliminarily. Aspects of the investigation (including duration and the numbers of tasks and sets) seemed appropriate for this study.

D. VIs

The basic sequence of providing VIs is to generate WAV files using a common microphone and the free software Audacity. To keep the speed of systems, the file size was made as small as possible (although the file sizes varied).

Each of real-time VIs and their triggers is in Table III; each length was around 8–9 seconds. We saved them as WAV files on a computer and played them back via a program written in Visual Basic. The users listened to the files as needed, and the VIs were considered to reflect ideal, typical motions of a mature (experienced) worker for each work task.

The criteria given in Table III were determined from preliminary data for mature subjects and comparisons between mature and immature subjects.

TABLE II. CATEGORIZATION OF AGRICULTURAL TASKS

Categorization of tasks	Description
1. Work in a sitting position	Cropping (picking) onions or garlic in a standing position Harvesting general root plants by hand; cumbersome, successive procedures (e.g., digging holes and overlaying clay, spraying water)
2. Work in a semi-crouching position	Cultivating (digging) with a hoe
3. Work in a standing position	Cutting branches with scissors and a saw
4. Work alternating between sitting and standing positions	Suspending onions or garlic on beams in an outhouse

TABLE III. REAL-TIME VIs AND THEIR TRIGGERS

Task	Target part	Content	Criterion
Picking onions in a sitting position	Lower arm (mainly dominant arm)	"Arm swing is too intensive."	1. or 2. is included in every time-span of two seconds. 1. Acceleration-X or acceleration-Y exceeds 2G 2. Acceleration-Z exceeds 1.5G
		"Angle of arm swing is inappropriate"	The average values of data of every two seconds are over the range of 1−3. 1. −0.4G < acceleration-X <1.05G 2. −0.1G <acceleration-Y 1.3G 3. −0.9G <acceleration-Z <1.4G
	Waist	"Pick yourself up"	The average values of timeline of 2 seconds is outside −0.35G < acceleration-X 1.15G.
		"Body is leaning forward (backward, to the right, left) to excess"	The average values of timeline of 2 seconds are outside the range of 1.−4. 1. 0.5G > acceleration-Y 2. −0.2G acceleration-Y 3. 0.13G > acceleration-Z 4. −0.13G < acceleration-Z
Suspending onions on a beam in a outhouse alternating between standing and sitting positions	Lower arm (mainly dominant arm)	"Arm swing is too weak"	Data do not exceed both thresholds 1. and 2. for each timeline of 2 seconds . 1. 0.15G > acceleration-Z 2. 0.65G < acceleration-Z
		"Angle of arm swing is inappropriate"	The average values of timeline of 2 seconds are outside the range of 1.−3. 1. −0.4G < acceleration-X < 0.8G 2. −1.1G < acceleration-Y < 1.0G 3. −0.4G < acceleration-Z ＜ 0.15G
	Waist	"Pick yourself up"	The average values of timeline of 2 seconds are outside the range of 1.. 1. −0.35G < acceleration-X < 1.15G
		"Body is leaning forward (backward, right side, left side) to excess"	The average values of timeline of 2 seconds are outside the range of 1.−4. 1. 0.5G > acceleration-Y 2. −0.2G < acceleration-Y 3. 0.13G > acceleration-Z 4. −0.13G < acceleration-Z
Digging up farm by a hoe in a semi-crouching position	Lower arm (mainly dominant arm), and left side of a hoe (15 cm distant from the gripping position of the dominant hand)	"Take your hoe with an appropriate angle"	The average values of hoe acceleration in each timeline of 1 second is outside the range of 1. 1. –0.7G < acceleration-Y < 0.7G
		"Dash your hoe more strongly"	The data of hoe acceleration do not be over threshold 1. for each timeline of 1 second. 1. 3.1G < acceleration-X
		"Use your hoe more strongly"	The data of hoe acceleration do not exceed threshold 1. or 2. for each timeline of 1 second. 1. angular velocity-Y < −150deg/s 2. angular velocity-Z < −150deg/s

Task	Target part	Content	Criterion
		"The hoe swing is too weak"	The length of hoe acceleration vector $((X^2+Y^2+Z^2)^{1/2})$ data do not exceed threshold. 1. more than three times per 5 seconds. 1. $((X^2+Y^2+Z^2)^{1/2}) > 3G$
		"The hoe swing is too intensive"	The length of hoe acceleration vector $((X^2+Y^2+Z^2)^{1/2})$ data exceed threshold 1. more than five times per 5 seconds. 1. $((X^2+Y^2+Z^2)^{1/2}) > 3G$
	Waist	"Pick yourself up"	The average values of timeline of 2 seconds are outside the range of 1. 1. $-0.4G <$ acceleration-X $< 1.2G$
		"Body is leaning forward (backward, to the right, left) to excess"	The average values of timeline of 2 seconds are outside the range of 1. 1. $-0.2G <$ acceleration-Y $< 0.5G$

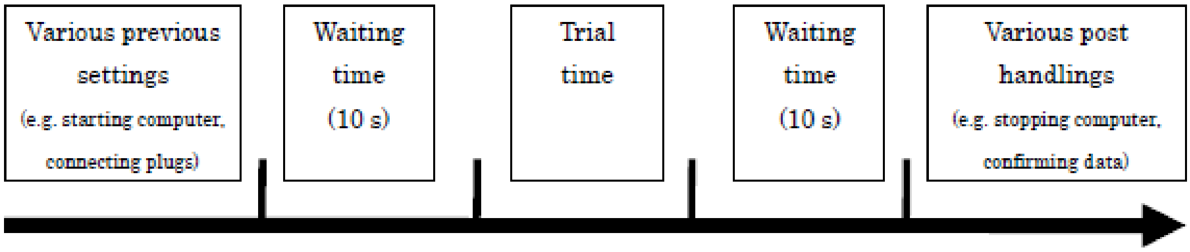

Figure 6. Timeline of each trial

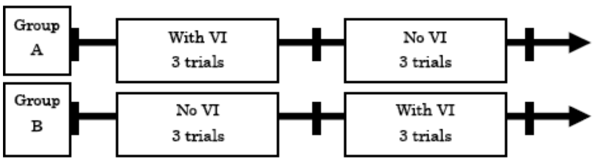

Figure 7. Timeline of trials for Groups A and B

E. Survey

We conducted a survey (four or five phases of evaluation and free comments) to determine the subjects' level of fatigue, discomfort with the system, and unseen, hidden information, immediately after all trials. The survey questions were designed and used by the Japan Society for Occupational Health and other major medical agencies.

TABLE IV. INDEXES OF OPTICAL FLOW ANALYSIS

Index	Code	Definition , description (feature)
Average	ave	OF average absolute length of speed vectors
Variance	var	Variance of speed vector length
Median	med	Median of absolute value of speed vector length
Mean value 0	mean0	Average of variance of speed vector length, deleting the bad effects from "pans" of camera work
Mean value 1	mean1	Average of variance of each of 12 blocks separated on the screen of speed vector length, deleting the bad effects from the movements of users back and forth
Max value 0	max0	The maximum vector length in the frame
Max value 1	max1	The top 1.5% percentile value of max0
Max value 2	max2	The top 10% percentile value of max0
Second-order differential	diff	Difference of accelerations of speed vectors between two successive frames

F. Indicators

After basic trials, we defined major indicators of acceleration in the vertical direction and optical flow (OF) analysis data (as CSV files): 1) the maximum value, 2) the minimum value, 3) the standard deviation (S.D.), and 4) the direct current (DC) component. Bao (2003) [8] and other researchers have used such indicators. In particular, S.D. and the DC component have been found to be useful. The indicators for the OF analysis are given in Table IV [10], [11]

III. Results and Discussion

We obtained important sequential data for the contributions to real outdoor workers in agricultural industries.

1) Experienced and inexperienced workers clearly moved their limbs and bodies in different ways. The experienced worker moved more smoothly and leaner (not so contained keen motions) than the inexperienced worker (see Fig 8). Their natural, unselfconscious working motions were more effective and sophisticated as a whole.

The time series of the arm acceleration of an experienced worker revealed longer periods of calm, but peaks in the time series were more dramatic and sharper, relative to those of the inexperienced worker. Hand transference (e.g., from cane to cane of vegetables, from swing to swing of digging motions) of the experienced worker was quicker and more acute, and the range of values of the pitch angular velocity (e.g., +151 to −250 deg/s) was wider than that of the inexperienced worker. Additionally, the experienced worker hardly hesitated in performing the next expected action, making alternately stronger and weaker motions using minimum energy.

In the case that the experienced worker cropped onions while in a sitting position, the accelerations along each of the three axes of the dominant arm were almost within ±2.0 G, in contrast to the case for the inexperienced worker. We believe that these results are due to the experience and skill of the experienced worker.

Considering such characteristics in three to five sets of timeline data, we set VIs and their criteria (triggers in programs) (see Table III). After giving VIs to inexperienced subjects, we recorded various changes (third plot in Fig. 8).

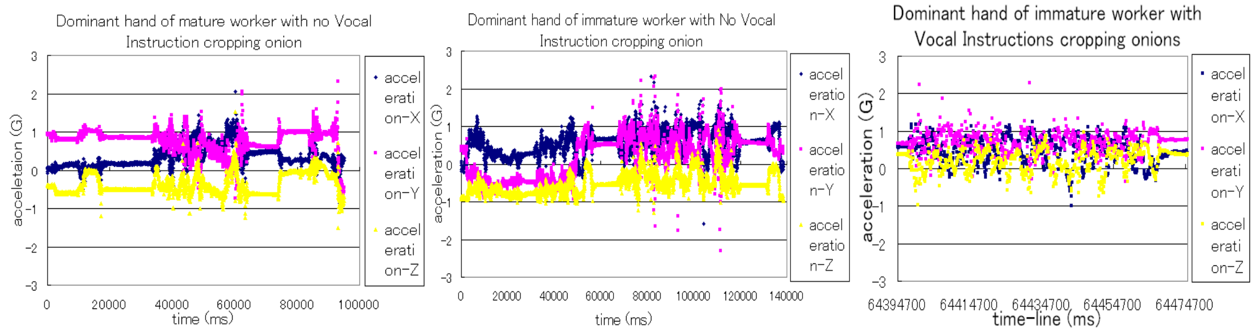

Figure 8. Timeline of the lower part of dominant hand acceleration data when subjects cropped onions while in a sitting position (first: experienced subject, second: inexperienced subject, and third: inexperienced subject with VIs)

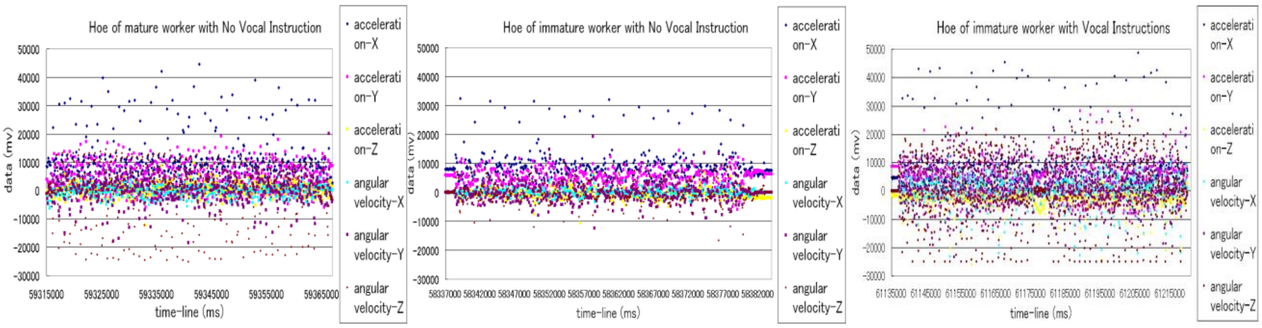

Figure 9. Timeline of hoe acceleration when subjects cultivated while in a standing position (first: experienced subject, second: inexperienced subject, and third: inexperienced subject with VIs)

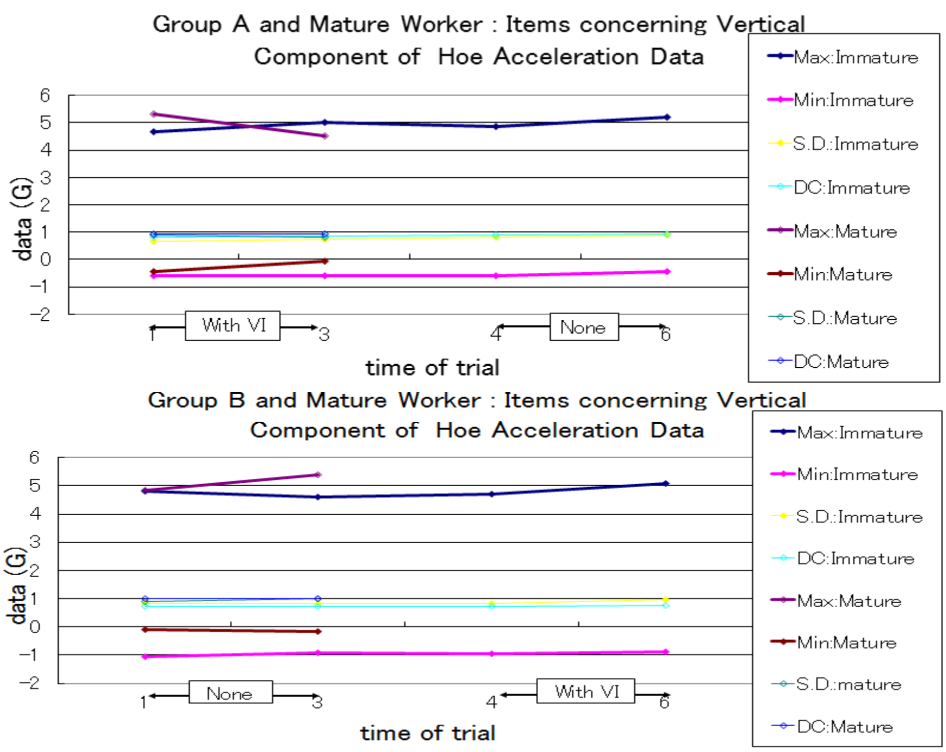

Figure 10. Timeline of the vertical component of waist acceleration (Upper: Group A and experienced worker, Lower: Group B and experienced worker); conditions of VIs are given

Without VIs, the range of acceleration along the three axes data often exceeded ±2.0 G. However, with VIs, the acceleration almost matched that of the experienced worker (almost entirely in the range ±1.5–2.0 G), and there were many favorable (becoming close to experienced worker) changes in almost all timelines.

In the case of the inexperienced worker cultivating (digging) with a hoe in a semi-crouching position, movements (values of acceleration and angular velocity) slightly approached those of the experienced worker judging from the overall temporal sequence of the data. For instance, in terms of the dispersion of values in timelines in the second plot of Fig. 9, values for the inexperienced worker without VIs were in a rather limited range for each variable.

In particular, the angular velocity along the three axes was strongly limited (those were in the small range), not enough, in other word inadequate digging actions. Values of angular velocity for the experienced worker were likely to be about 1.5 times those of the inexperienced worker; the range of vertical acceleration was likely to be about 1.4 times that of the inexperienced worker. However, the third plot of Fig. 9 (for the inexperienced worker receiving VIs) was close to the results for the experienced worker. This is considered to be a good change. Overall, the times of VIs that have sent from PC to inexperienced subjects were about 1.1–1.5 times more than experienced them, according to each tasks.

2) In the case of digging up soil with a hoe while in a semi-crouching position (see Fig. 10 and Fig. 11), maximum and minimum data values of experienced and inexperienced subjects were changed in the reverse directions concerning hoe vertical acceleration.

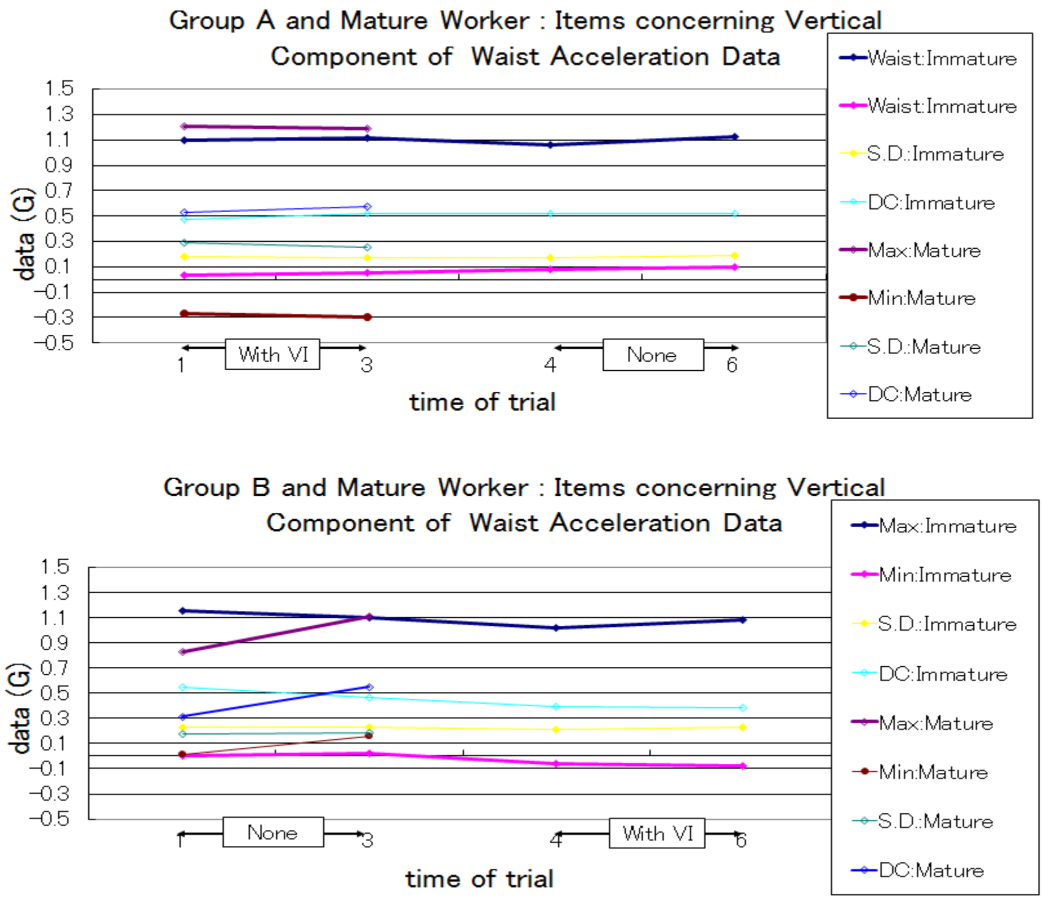

Figure 11. Timeline change

We believe that this is because movements approached the intended, ideal movements (defined from experienced subject's movements). The S.D. and DC component slightly increased for each group. This was perhaps because the subjects got into the swing as they warmed up. These characteristics were common to both the hoe and waist acceleration data.

The range of the waist vertical acceleration of the experienced subjects was much wider than that of the inexperienced subjects. (Concerning the data while hoe swing, those were also similar tendencies.) In other words, the inexperienced subjects moved their waists (trunks) on a grand scale, widely. This feature was observed as one of the most important points related to skill when lecturing inexperienced workers.

Overall, as for group A, each of the four indexes were likely to decrease slightly after VIs were given, but these good changed conditions were likely to remain after then for the time being. This important phenomenon was observed as the durability of the VI effect.

Furthermore, it seemed that users can also obtain the benefits of VIs to some extent, only by short-term use.

Group B members were likely to work anemically and carelessly while no-VIs–terms. This might be due to fatigue and tiring, but after they received VIs, the subjects apparently recovered in terms of the momentum of their movement. We observed them the natural phenomena (recovery), while at the same time, we should collect more data on accuracy and power to improve the system.

4) Average values derived from OF analysis are given in Table V. The values of OF vectors for the experienced worker are larger those of the inexperienced worker; in particular, values of second-order deltas (second-order differential values) are superior for almost all OF indexes of the two tasks.

There were also apparent differences in values for the different groups. Almost all OF numerical values relating to different items for the experienced worker were higher than those for the inexperienced worker in the two tasks. We believe that this is because of the aforementioned reasons of experience and no hesitation.

We also calculated the difference between two conditions with and without VIs concerning the same subjects, and the difference with experienced subject (without VIs) (see the gray and orange rows).

As for the changes in data (for both the hoe and waist), we could certainly observed effects to make difference with experienced data smaller by this system. However, such changes were a little excessive, so we should think any ways to re-revise such over-changes.

5) All subjects rated all items in the survey from 1 (easy) to 3 (mild) on a five-point scale, reflecting that they did not feel serious fatigue or discomfort when using the system in this study.

TABLE V. OF ANALYSIS

Task	Trial times	ave	var	med	mean0	mean1	max0	max1	max2	diff
Experienced subject without VIs										
Picking onions in a sitting position	3	0.065	0.143	0.021	0.075	0.061	2.590	0.606	0.157	0.073
Digging with a hoe in a semi-crouching position	2	0.072	0.177	0.023	0.083	0.077	4.610	0.747	0.157	0.077
Experienced subject with VIs										
Picking onions in a sitting position	1	0.064	0.131	0.027	0.067	0.057	2.854	0.537	0.147	0.074
Digging with a hoe in a semi-crouching position	3	0.074	0.177	0.02	0.09	0.073	2.94	0.775	0.174	0.078
Inexperienced subjects without VIs										
Picking onions in a sitting position	3	0.053	0.132	0.014	0.064	0.054	2.952	0.541	0.120	0.058
Difference from experienced subject without VI	–	−0.012	−0.011	−0.007	−0.011	−0.007	0.362	−0.065	−0.037	−0.015
Digging with a hoe in a semi-crouching position	2	0.070	0.158	0.021	0.081	0.074	3.723	0.674	0.166	0.072
Difference from an experienced subject without VI	–	−0.002	−0.019	−0.002	−0.002	−0.003	−0.887	−0.073	0.009	−0.005
Inexperienced subjects with VIs										
Picking onions in a sitting position	2	0.090	0.213	0.023	0.111	0.089	4.602	0.851	0.25	0.107
Difference from the same subjects without VI	–	0.037	0.081	0.009	0.047	0.035	1.650	0.310	0.130	0.049
Difference from an experienced subject without VI	–	0.025	0.070	0.002	0.036	0.028	2.012	0.245	0.093	0.034
Digging with a hoe in a semi-crouching position	4	0.086	0.196	0.022	0.104	0.088	3.14	0.856	0.221	0.095
Difference from the same subjects without VI	–	0.016	0.038	0.001	0.023	0.014	−0.58	0.182	0.055	0.023
Difference from an experienced subject without VI	–	0.014	0.019	−0.001	0.021	0.011	−1.470	0.109	0.064	0.018

IV. CONCLUSION AND FUTURE WORK

Our study constructed and demonstrated the aforementioned integrated styles of systems (contact and non-contact systems unified) consisting of low-cost, common (non-specific) substances) and methods employed at actual work sites. Additionally, we obtained various promising results, especially concerning providing successive VIs to actual inexperienced workers, and the subsequent positive effects. Focusing on traditional skills and related daily tasks, we verified the usefulness of our system.

The performance of our system was verified only for the limited movements targeted in this study, not including movements of translation such as walking or running.

We revealed future prospects of combining agricultural informatics, general statistics, and human dynamics to some extent. Reviewing the entire results and work products, we will prove that the measure of precision for diagnosing poor motions and postures, and for skill tradition will be improved.

However, the validity, endurance, precision, and long-term effects of our system must be further confirmed in future work; above all, we need to include a greater variety of worker data as statistical data. We must observe the "over response" and "excessive movement" in response to VIs, particularly concerning inexperienced users (in this study, those were characteristic of relatively young users).

Other methodological settings (e.g., other timelines, other kinds of hoe, other field conditions, indoor spaces, in rain, and singular subjects), recent methodologies of human dynamics and visual data analysis should be tested and incorporated. The stability, size, weight, adhesion, and cost of our overall system will also be improved in the future.

We have many plans to apply our system to other natural outdoor farms and other industries (situations), and to launch practical supporting projects for workers. By combining WSs and OF, we shall develop more comprehensive mechanisms. The aforementioned trials remain a challenge at least for now, but we will cover worker contributions and traditional skills of agricultural industries.

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