

Effect of Instructions on Parts' Positions during an Assembly Task on Efficiency and Workload

Kojiro MATSUSHITA *, Keita NIWA *, Satoshi ITO *, and Minoru SASAKI *

Abstract: This paper examines the effect of instructions on parts' positions during an assembly task having numerous parts for someone to remember where they are located. Hypothesizing that instructions relating to the positions of the parts would enhance work efficiency and reduce workload, we designed an experimental method to test this theory. In this experiment using educational blocks, visual instructions were given by illuminating the space where the parts are kept, while auditory instructions were provided to aid locating the parts to compare the efficiency of visual and auditory instructions. Experiments with six participants showed that the visual instruction significantly shortened not only the search time but also the assembly time (which was one way in which efficiency was assessed in this study). The use of parts' positions instructions tended to reduce the workload as evaluated with NASA-TLX compared with the cases without instructions.

Key Words: assembling task, instruction, efficiency, workload, parts' position.

1. Introduction

The development of industrial technologies has brought about mechanization and automation of processes enabling mass production. However, small production volumes of limited or special products are also commercially effective as they enable unique or elaborate details to be added that are highly valued as they render the special products distinguishable from mass produced products.

The small volume production of various special products is realized by so-called cell production, where a few workers (or even just one) have to perform many types of tasks one by one. In such a production system, one worker engages in various operations. In addition, the production processes are frequently modified because only a small number of products are being manufactured. Thus, there are few opportunities for workers to conduct all the operational procedures before they remember the entire production processes. Accordingly, workers will often glance at the instructional process sheets while performing their tasks. Frequently checking the instructional process sheets will reduce the efficiency of the operations, eliminate the rhythm in a series of operations, and disturb the concentration compared with flow production in which the same simple tasks are performed repeatedly. Non-rhythmical operations may make the workers uncomfortable, which is a potential cause of mental stress. Establishing an environment where the workers can continue their task without any stress is necessary not only to increase the efficiency of the task but also to improve work environment.

Many past studies have focused on improving the productivity of cell production from several viewpoints. Digitalization or information technology is one noteworthy approach [1],[2]. Workspace configuration, task scheduling, and workers' education are investigated for a few workers in cell production. To

schedule on-the-job training, Haraguchi et al. [3] introduced a skill index and demonstrated that labor allocation based on this index efficiently improved the skill level of labors in computer simulations. Tanimizu et al. [4] proposed two types of learning or familiarization, namely operational familiarization and knowledge familiarization, and demonstrated that the acquisition of knowledge during tasks shortens the assembly time effectively. Kasumo et al. [5] considered buffer stations for shared tasks among the divided cells and discussed the conditions required to maximize their effects. Dong et al. [6] designed a self-evaluation sheet to measure workers' aptitude to investigate how aptitude affects the productivity of assembly tasks in production cells. Recently, collaboration of human and robot workers has been attempted to improve the productivity in cell production [7].

The final objective of our project is improving the productivity of manufacturing tasks. Our approach is related to the working environment, i.e., to introduce instructions that facilitate finding the parts to be assembled. The idea originated from the observation of a child playing educational blocks. When assembling a big product according to an instruction book, one of tough tasks is to find a required block at the current building stage, because there are lots of blocks with similar size and color. When a parent helped the child with finding a block, the child concentrated on the play: However, if it takes a lot of time for the child or parent to find it, the child used to get bored easily. It implies that the easy finding of the block may enhance the concentration of the workers, resulting in an efficient and stress-free work. Therefore, we hypothesize that in a complex assembly task in which the workers cannot memorize the assembly processes, positional instructions regarding the location of the parts will enhance the task's efficiency as well as make the work more comfortable for the worker because of reduced mental stress. Previously, we conducted an experiment in which we restricted instructions to visual and/or auditory during an assembly task in which educational blocks were used to investigate the effect of the parts' positions in-

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structions [8]. However, because some results left room for re-consideration, an additional experiment was conducted. Here, we report a new interpretation of the previous data based on the results of an additional experiment presented in this paper.

2. Experiment [8]

2.1 Hypothesis

We hypothesized that if an assembly task is too complicated for a worker to remember the entire process, explicit instructions regarding the location of the assembly parts might enhance the efficiency of the operation, reduce workload, and provide a more comfortable working experience. We aimed to test this hypothesis through a series of comparative assembly tasks in the laboratory. We examined the effects of an auditory, a visual, and an audio-visual set of positional instructions.

2.2 Concept

We simulated an assembly task with an educational block system owing to safety and cost. During the experiment, the operation time and its workload were evaluated. The latter was obtained via some questionnaires immediately after each assembly task.

All the parts for the assembly tasks were placed at a fixed position in the workspace. Each participant had to search and find the required part during the assembly process. The unique position was assigned for each part in advance; however, the positions of the blocks appeared random to the participants. Some unnecessary parts were also included so that the participant would not remember the order of the parts. In the experiment, products were assembled step by step by placing the designated parts in their designated positions. Some of the parts had the same shapes but different colors. The colors of the parts had no mechanical effect on the difficulty of the assembly task as the task complexity depended only on the shape of the parts, not their color. Thus, using a variety of colored parts enabled us to retain the difficulty of needing to search for parts without affecting the difficulty of the assembly task; repetitive usage of the same parts allows the participant to remember their positions, which reduces the search time for those parts.

We asked each participant to conduct the assembly process according to the process sheet as quickly and accurately as possible in the specified sequence. Then, to evaluate the efficiency, the operation time was measured separately to the search and assembly time.

At the start of each assembly task, all the parts were in the same locations each time. We examined two types of instructions: visual instructions in which the space of the required part was illuminated and auditory instructions in which a voice described the location of each part.

Based on our hypothesis, we tested for the following outcomes:

- (1). The visual or auditory instructions shorten the search time.
- (2). If the search time has been shortened, the assembly time is also shortened.
- (3). If the search time has been shortened, the workload is also reduced.

We are going to examine the above three predictions by the experiments.

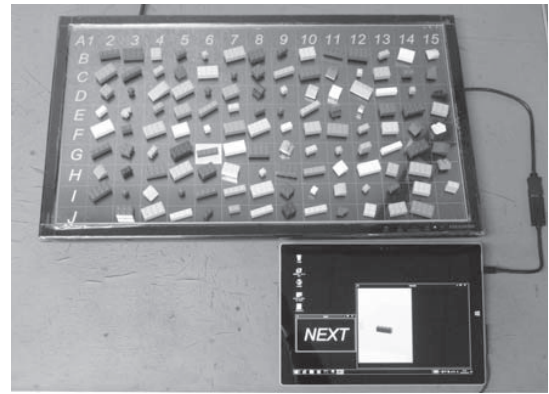
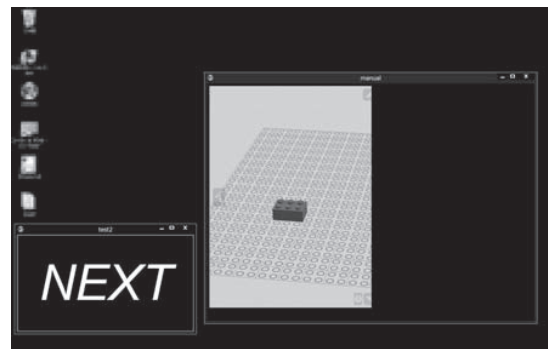
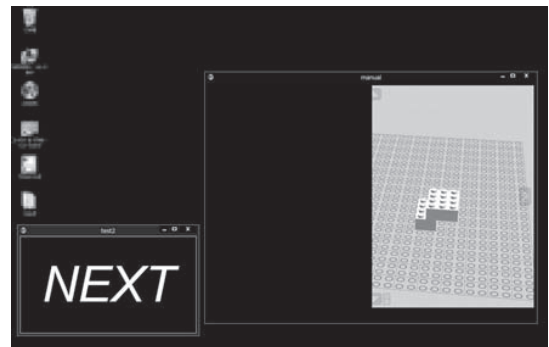


Fig. 1 Experimental setup.



(a) search phase



(b) assembly phase

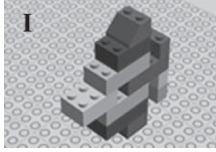
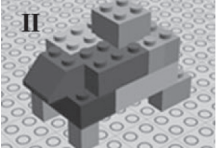
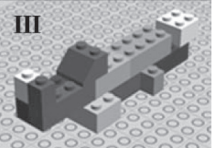
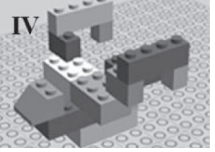
Fig. 2 An electronic process sheet.

2.3 Experimental Setups and Methods

In our experiments, LEGO (Creative Suitcase) was used for the assembly tasks. A parts plate was divided into many square part spaces and installed at a fixed position in the workspace. The parts (blocks) were each placed on a square space in a fixed order, as shown in Fig. 1. A unique address was assigned to each part space by labeling the space from A to J in the vertical, and from 1 to 15 in the horizontal direction. We utilized the flat panel display of a personal computer (PC) for the parts plate, which enables us to illuminate the parts space independently under the PC's control. Thus, the visual instructions can illuminate the part space by controlling the PC display. In contrast, the auditory instructions were created by calling the address of the parts position using the PC audio speakers.

The task starts by displaying the necessary parts on the electronic process sheet. The participant has to find the part required for the current process, which is graphically displayed in the left column as shown in Fig. 2 (a). Then, the space of this part may be illuminated or the address of this space may be

Table 1 Experimental planning.

Instruction(s)	Condition-A	Condition-V	Condition-N	Condition-B
	Audio	Visual	None	Audio and Visual
Final Product				
Task 1	1st	2nd	3rd	4th
Task 2	5th	6th	7th	8th
Task 3	9th	10th	11th	12th

read out loud depending on the experimental condition. When the participant has found the part, the participant is instructed to pick it up and press the NEXT button on the touch panel. At this moment, the time is recorded as the finish time of the searching phase, $t_1^{(n)}$. Here, n denotes the number of the process.

When the NEXT button has been pushed, the assembly drawing is shown in the right column as depicted in Fig. 2 (b). The participant is asked to assemble the products using the parts as indicated by this drawing and then push the NEXT button again when the participant has finished the assembly process. This causes the time to be recorded, which is the finish time of the assembly phase, $t_2^{(n)}$, and thus, one assembly process ends. At the same time, the next assembly process starts by displaying the part required for this process. The participant completes a product by repeating these processes.

By regarding the finish time of the assembly phase as the start time of the next process, the search time $T_s^{(n)}$ and the assembly time $T_a^{(n)}$ are defined by the following equations:

$$T_s^{(n)} = t_1^{(n)} - t_2^{(n-1)}, \quad (1)$$

$$T_a^{(n)} = t_2^{(n)} - t_1^{(n)}. \quad (2)$$

Immediately after the completion of one product, some questionnaires about the workload were conducted, where six factors were evaluated in ten grades based on the NASA-TLX [9].

An overview of the experimental setup is shown in Fig. 1. In total, 126 parts were placed on the parts plate over the horizontal flat panel display. Here, we regard the number of parts as being sufficiently large not to be able to memorize their shape and position. The tablet PC on the table served as the processor of the experimental measuring program in addition to the electronic process sheet. This PC was operated with Windows 8.1, the block assemble simulator LEGO Designer was used to create the electronic process sheet, and the measurement program was developed with the scripting language Tcl/tk.

2.4 Conditions

There were four conditions for the instruction setup: visual instructions only (Condition-V), auditory instructions only (Condition-A), both visual and auditory instructions (Condition-B), and no visual or auditory instructions (Condition-N).

We created three tasks to examine the differences with respect to the difficulty of the task. In one of the tasks, the participants assembled the parts as instructed in the process sheet

(Task 1). Another task was the same as Task 1 but included an additional adjustment of the block orientation to direct the logo on the block in the same direction (Task 2). Further, there was a task in which the participants could stack the blocks as they liked, neglecting the process sheet instructions (Task 3). We expected Task 2 was the most difficult and Task 3 was easier than Task 1.

The participants have to complete a product under four different conditions for Tasks 1 - 3, giving a total of 12 productions in each experiment. The details of the final products for each condition are listed in Table 1. All the products comprise exactly the same 13 parts in order to remove the effect of different parts. Parts with different colors were intentionally combined to prevent the participant from predicting the next parts. In addition, the final shape of the product is not shown until the last process to ensure the unpredictability of the parts' positions.

Six healthy male participants aged 20 to 24 years were recruited for this experiment. The experimental protocol was approved by the Ethical Review Board of Gifu University Graduate School of Medicine (27-224).

3. Results and Analyses

3.1 Search Time

In this experiment, the number of parts decreases as the assembly tasks progresses, which may facilitate the finding of the parts unless a sufficient number of parts remain in the workspace. Thus, the search times were evaluated in every process. Figure 3 shows the search time of each process averaged over all the tasks, conditions and participants, together with its standard error. Although the search time of the first process is longer than that for the others, it does not decrease as the assembly task progresses. This indicates that a sufficient number of parts were included in this experiment, and thus, we can rule out the effects of the decreasing number of parts on the search time.

Next, to investigate the effect of the instruction conditions, the search time was averaged over the tasks and participants for each condition. The results are shown in Fig. 4 along with their standard errors. A significant difference was found between the four instruction conditions according to ANOVA ($F(3, 15) = 25.001, p < 0.001$). Thus, post hoc analysis was conducted using Tukey's test, which showed that the visual instruction significantly reduced the search time. In contrast, Condition-A (only the auditory instruction) showed no differ-

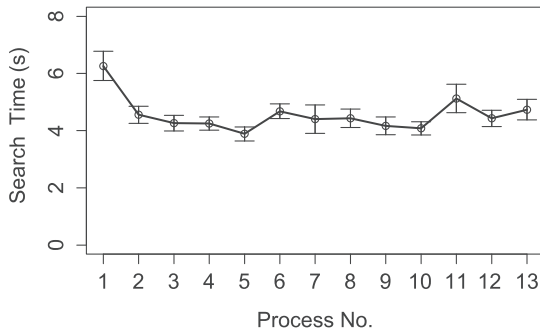


Fig. 3 Search time with respect to assembly process.

ence from Condition-N (no instructions).

Finally, ANOVA was applied to determine the search times of the three tasks. We did not find that there was a significant difference between the tasks ($F(2, 10) = 1.301, p > 0.3$).

3.2 Assembly Time

Three tasks were designed to have different difficulties. This should be reflected by the assembly time. Figure 5 shows the assembly time averaged over all the instruction conditions and the participants for each task. ANOVA revealed that the assembly time is significantly different for these three tasks ($F(2, 10) = 12.326, p < 0.01$). The following Tukey’s test indicated that the assembly time of Task 2 is different from that of the other two tasks ($p < 0.001$). No differences were found between the time for Tasks 1 and 3 ($p > 0.9$).

Next, the effect of the instructions regarding the parts’ positions was examined. The analysis of all the obtained data seemed to indicate that the instruction conditions had few effects on the assembly time; ANOVA indicates no significant difference in assembly time with respect to the instruction conditions ($F(3, 15) = 0.484, p > 0.69$). However, we have found that Task 2 extended the assembly time significantly in comparison to the others. In Task 2, it took a lot of time to change the part orientation since the smallness of the logo makes it difficult to recognize the logo. Especially, it seemed that the ease of the logo recognition depended on the block color, and some blocks had unclear ones. In addition, the manipulability of the block orientation also seems to depend on the size or the shape of the blocks. Namely, it was highly likely that these factors affected

the variance of the assembly time including the manipulation for the block orientation more largely than the difference in the positional instructions. This is why we removed the data for Task 2 in the next assembly time analysis, although we had originally intended to distinguish the task by its difficulty level.

Although no significant differences were obtained from ANOVA ($F(3, 15) = 1.853, p = 0.181$), Tukey’s test indicated that the assembly time differed significantly ($p < 0.01$) between Condition-V and Condition-A as well as between Condition-V and Condition-N. However, no differences were found between Condition-B and Condition-A as well as between Condition-B and Condition-N [8], although there should have been differences according to the 2nd hypothesized outcome as the search time had decreased in that case.

This caused us to doubt our assumption that the difficulty levels were the same across all the four products, which we made based on the fact that they comprise exactly the same block components. Therefore, we measured the normal assembly time to make sure that it was not affected by the search process. The details of the experiments are described in the appendix A. Unfortunately, the results indicate that the assembly times were not the same: the assembly time of Product III was larger than that of Products I and II.

Based on this finding, we evaluated the assembly time after

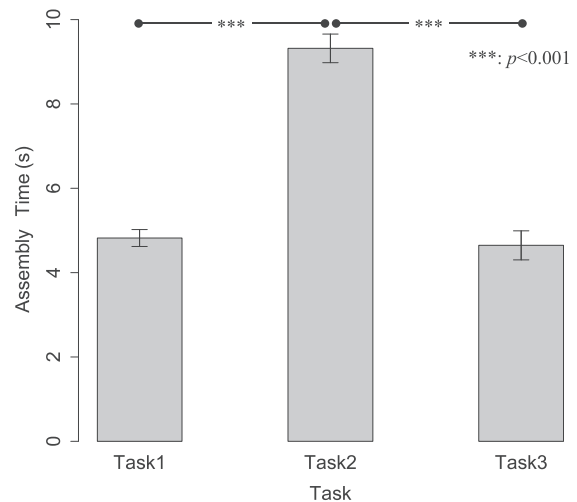


Fig. 5 Assembly time for three different tasks.

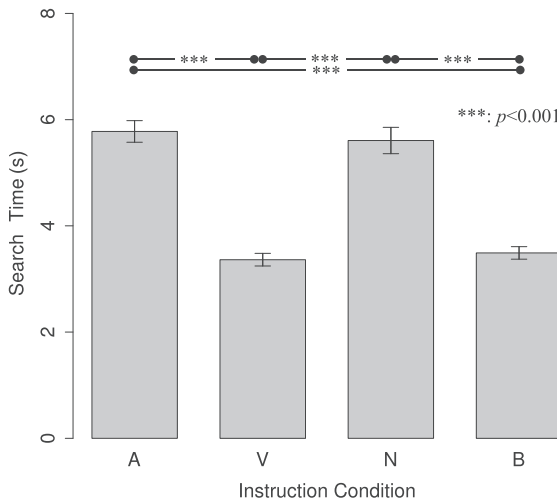


Fig. 4 Searching time vs. instruction conditions.

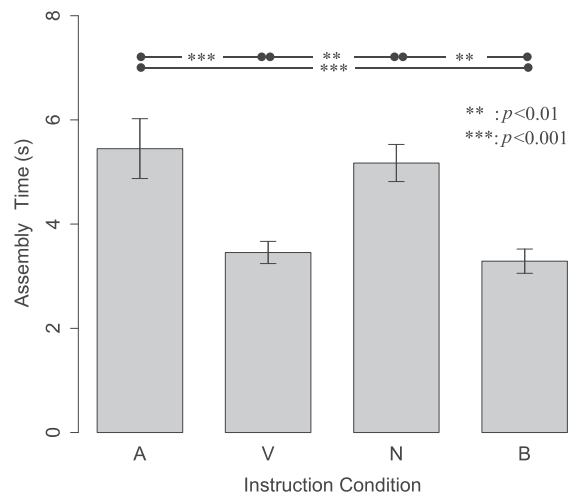


Fig. 6 Assembly time for different instruction conditions.

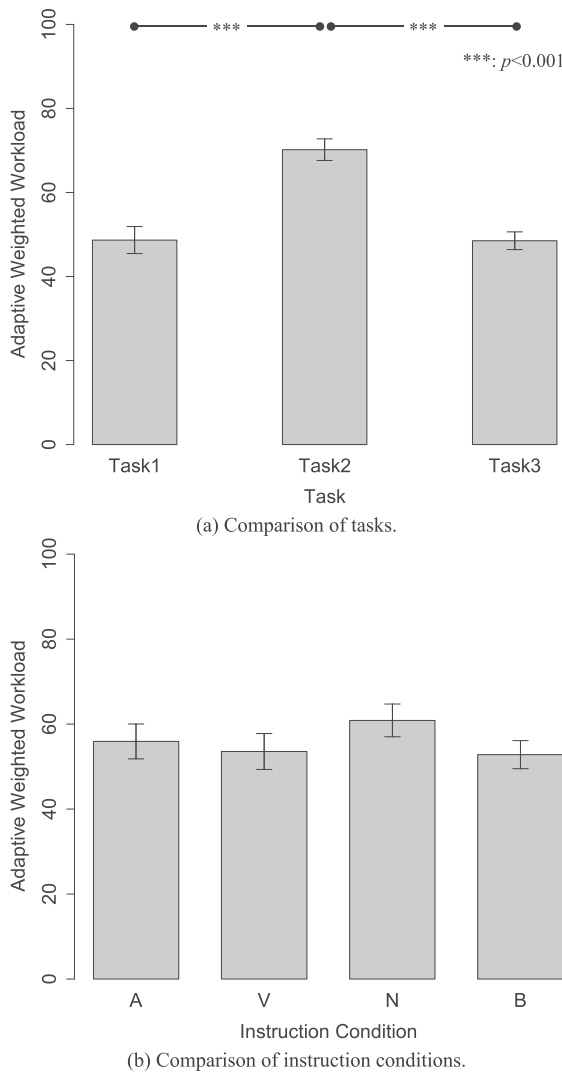


Fig. 7 Workload evaluation based on NASA-TLX.

correcting the data with regard to the ratio between the values with and without outliers in Table A.2. The result of this comparison is shown in Fig. 6. In Tukey's test, we found the same significant difference as for the search time, as mentioned in the 2nd hypothesized outcome.

3.3 Workload

Workloads were evaluated via the adaptive weighted-sum scores of six NASA-TLX questionnaires, giving us the adaptive weighted workload (AWWL) values [10].

The averaged scores of each task are shown in Fig. 7(a). Freidman's test denoted a significant difference ($\chi^2 = 30.58$, $p < 0.001$). The post hoc analysis indicated that the workload for Task 2 was significantly high ($p < 0.001$).

In contrast, the averaged scores of each instruction condition are compared in Fig. 7(b). There are no significant differences based on Freidman's test ($\chi^2 = 4.05$, $p = 0.256$); however, the AWWL score seems slightly smaller with an instruction for the parts' positions than without instructions. The Wilcoxon rank sum test between Condition-N and the others denotes that the AWWL average score without Task 2 data differs from the score of Condition-N with $p = 0.04273$.

4. Discussion

The search time decreased for both Condition-V and Condition-B where visual instructions were available compared with the results for Condition-N in which only the electronic process sheet was used. However, Condition-A with only the auditory instructions did not produce a difference in search time compared with Condition-N. Some reasons for there being differences between the visual and auditory instructions are likely that the auditory messages were easy to mishear, and some participants seemed to concentrate on listening out for the instructions rather than on searching as they were meant to; in addition, the participants could not start searching until the auditory message finished. In this experiment, all parts were placed in a relatively narrow area that the participants could observe all at once. Therefore, the participants did not have to adjust their line of sight. If they had to switch their gaze, auditory instructions such as beeping sounds from the direction of the parts would likely be effective. Thus, this result will depend on the experimental protocol. Regardless, we can conclude that the visual instructions were more effective in this experiment.

Next, we discuss the assembly time. Initially, we expected the assembly time to show differences with respect to the instruction conditions regardless of the task difficulty. However, the analysis indicated that there were no significant differences between the four instruction conditions. Thus, we restricted the range of the analysis to only Task 1 and Task 3, which showed no differences in the assembly time. Task 2 includes the operation of making sure that the logo direction is uniform: this task may be more difficult than the assembly itself, which might affect the analysis.

Although the Task 2 data were removed, no significant difference appeared between Condition-B and Condition-A as well as between Condition-B and Condition-N with respect to our hypothesized outcomes. As we could not determine any other possible reasons, we evaluated the difficulty of assembly for each final product. As a result, the normal assembly time was not the same for all the products, and thus, we corrected the data using the ratios of the assembly time with and without outliers; the data sets with outliers represent naturally observable averages containing some incidents and accidents that the participants sometimes encounters whereas the data sets without outliers can be regarded as estimates of true assembly time. Thus, we expected that multiplying the observed value by their ratios will remove the difference of the assembling difficulty in the final products since the ratios differs in each instruction condition. Although we obtained good analytical results, the data correction method seems sensitive to the values of the outliers. The assembly time might be re-evaluated by considering the experimental design so that every final product should be assembled for each instruction condition.

Finally, regarding the workload, no significant differences were detected for the various instruction conditions. However, the tendency for some positional instructions to reduce the workload can be observed: all the workloads were evaluated to be lower than that without instructions.

In summary, we found some evidences for our hypothesized outcomes (1) and (2) in Section 2.2. In an assembly task in this paper, visual instructions shortened not only the search time but also the assembly time. However, the workload, as evaluated by

NASA-TLX, was not affected much by the specific instructions used but tended to be large without any instructions. Further investigations are required to evaluate the hypothesized outcome (3).

5. Concluding Remarks

In this paper, we discussed the effect of instructions for the positions of parts in a situation where there are too many parts to remember their storage locations. We designed a method to examine our hypothesis that instructions regarding the location of parts enhance the efficiency and reduce the workload. The experiment comprised assembling educational blocks. Six participants were used to evaluate how a visual instruction illuminating the parts space and/or an auditory instruction announcing the address of the parts space affected the search time, the assembly time, and the workload (as assessed with NASA-TLX). The results are as follows.

- A visual instruction of the parts’ positions shortens the search time.
- The assembly time also tends to be reduced by the instruction that reduced the search time, i.e., the visual instruction. Especially, the reduction is significant in the single application of the visual instruction.
- Positional instructions have an effect on reducing the workload compared with using no instructions.

Regarding the second concluding remark, we also obtained the significant reduction of the assembly time for the task applied by both audio and visual instructions after our data correction based on the additional experiments. Instead of this data correction, however, we should have improved the design of the original experiment so that each final products were instructed in a different manner in order to remove the effect of the difference in the assembling difficulty among the final products.

In addition, further investigation into the workload is required. In future work, we would therefore wish to evaluate the workload in relation to bio-signals and discuss the relationship between the task instructions, performance, and mental stress.

Acknowledgments

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References

[1] S. Seki: One by one production in the “digital yatai”, *Transaction of the JSME (in Japanese)*, Vol. 106, No. 1013, pp. 254–258, 2003.

[2] M. Sugi, M. Nikaido, Y. Tamura, J. Ota, T. Arai, K. Kotani, K. Takamasu, S. Shin, H. Suzuki, and Y. Sato: Motion control of self-moving trays for human supporting production cell “attentive workbench”, *Proceedings of the 2005 IEEE International Conference on Robotics and Automation, 2005, ICRA 2005*, pp. 4080–4085, 2005.

[3] H. Haraguchi, T. Kaihara, and N. Fujii: A study on operator allocation aiming at the skill improvement for cell production system, *Transaction of the JSME (in Japanese)*, Vol. 81, No. 825, 14–00646, 2015.

[4] Y. Tanimizu, S. Ishii, T. Yokotani, K. Iwamura, and N. Sugimura: Development of a work instruction system based

on analysis of learning processes for cellular manufacturing, *Transaction of the JSME (in Japanese)*, Vol. 80, No. 814, TRANS0142, 2014.

[5] S. Kasmō, T. Ikeda, and T. Enkawa: A study on elucidation of complementary effect between helping zone system and introduction of buffer stations in cell manufacturing, *Journal of Japan Industrial Management Assoc.*, Vol. 64, No. 3, pp. 472–479, 2013.

[6] Y. Dong, X. Hao, S. Sato, and V. Kumar: An attempt and issues to measure workers’ aptitude toward assembly tasks in production cells, *Proceedings of the IEEE 2015 International Conference on Logistics, Informatics and Service Sciences (LISS)*, pp. 1–5, 2015.

[7] R. Kato, M. Fujita, and T. Arai: Development of advanced cellular manufacturing system with human-robot collaboration, *19th IEEE International Symposium in Robot and Human Interactive Communication*, pp. 355–360, 2010.

[8] K. Matsushita, K. Niwa, S. Ito, and M. Sasaki: An experiment to evaluate audio-visual instructions about parts position in an assembling task, *Proceedings of the SICE Annual Conference 2016*, pp. 679–684, 2016.

[9] S.G. Hart and L.E. Staveland: Development of NASA-TLX (task load index): Results of empirical and theoretical research, *Advances in Psychology*, Vol. 52, pp. 139–183, 1988.

[10] S. Miyake and M. Kumashiro: Subjective mental workload assessment technique-An introduction to NASA-TLX and SWAT and a proposal of simple scoring methods-, *Transaction of Japan Ergonomics Society*, Vol. 29, No. 6, pp. 399–408, 1993.

Appendix Additional Experiment

Eight participants were recruited for this experiment and were asked to assemble each of the four final products (I to IV in Table 1). The purpose of the experiment was to compare the normal, or standard, assembly time of each of the four products. All of the 13 block components were exactly the same for the four products. Thus, only 13 parts with the same color were picked up and were placed in the appropriate positions for the participants in the workspace. The participants were asked to assemble the product according to the electronic process sheet in Fig. 1 in the same manner as described in Section 2.3. Note here that no position instructions were required in this experiment since all the 13 products were already picked up in advance. The searching time as well as the assembly time were measured.

The search time results are summarized in Table A.1 with the sample number *N*. The search times were all around 2 s and, as we expected, there were no significant differences among the conditions from I to IV.

Table A.1 Search time in additional experiment.

	<i>N</i>	ave ± sd
Final product I	104	2.12 ± 0.86
Final product II	104	1.93 ± 0.93
Final product III	104	2.12 ± 1.03
Final product IV	104	2.29 ± 0.92

Table A.2 Assembly time in additional experiment.

	raw data		no outliers	
	<i>N</i>	ave ± sd	<i>N</i>	ave ± sd
Final product I	104	4.38 ± 2.00	104	4.38 ± 2.00
Final product II	104	4.35 ± 2.31	104	4.35 ± 2.31
Final product III	104	5.35 ± 2.91	103	5.20 ± 2.52
Final product IV	104	7.14 ± 10.40	96	4.98 ± 2.52

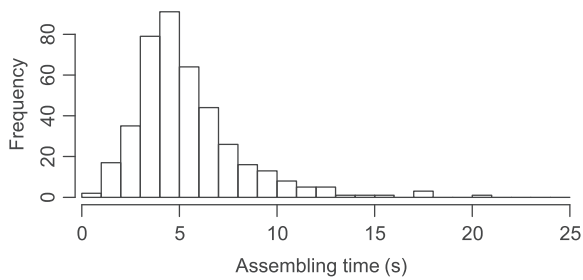


Fig. A.1 Histogram of assembling time from 0 s to 25 s. Not shown in this histogram, three data exceed 25 s.

However, there were large differences in the assembly time, unlike in our assumption, as shown on the left in Table A.2. An assembly time of over 30 s occurred several times. In those cases, the block product was broken, i.e., some parts dropped out of the product during the task and thus the participants had to repair it. As shown in Fig. A.1, the frequency of the assembly time data in 1s-interval histogram was decreasing in the range over 4s, and became zero at around 15s once. Assembly times over 10 s existed even for products I and II where the average of the assembling time was comparatively short. Therefore, values over 15 s were regarded as outliers. The averages of the assembly times without the outliers are shown on the right in Table A.2. Tukey's test revealed that there are significant differences ($p < 0.05$) between products I and III and between products II and III.

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