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An Experiment to Evaluate Audio-Visual Instructions about Parts Position in an Assembling Task

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Abstract: This paper examines an effect of parts position instructions in an assembling task where the number of the parts is too large to memorize their storage location. Hypothesizing that an instruction of the parts position enhances the work efficiency and reduces the workload, we attempt to design an experimental method to demonstrate its validness. In this experiment using educational blocks, a visual instruction is given by illuminating the parts space and an auditory instruction is provided by voicing the part space address. Six participants' experiments will show that the visual instruction significantly shortens not only the searching time but also one of the efficiency assessments, the assembling time, and tends to decrease the workload evaluated with NASA-TLX.

Keywords: human measurement, assembling task, instruction, efficiency, workload,

1. INTRODUCTION

The development of industrial technologies has brought the mechanization or the automation enabling the mass production of the same products. On the other hand, the small production of the limited or special products is an effective approach in the opposite side in which the uniqueness or the elaborateness are highly evaluated as new additional values distinguishable from the mass products.

The latter small production of the various special products is realized by so-called, a cell production, where one or a few workers have to achieve a many kinds of tasks one by one. In such a production system, the tasks that one worker engages in are diverging to an abundance of operations. In addition, the production process are frequently modified due to the smallness in the number of the manufacturing products. Then, the workers have to conduct various operations before they remember all the production processes or operational procedures. Accordingly, the operation will be supposed to become the one that accompanies referential glances of the process sheets. The frequent glances of the process sheets will reduce the efficient of the operations and eliminate the rhythms in a series of operations, and disturb the concentration in comparison to the flow production consisting of the repetition of the same simple tasks. Non-rhythmical operations may provide the workers with uncomfortability, which becomes a possible reason for the mental stress. To establish an environment where the workers can continue the task without the stresses are being necessary not only from the efficiency of the task, but also from the improvement of the work environments. Many papers are considering the improvement of the cell production from several points of view [1-3].

In this paper, we hypothesize that, in a complex assembling task whose assembling processes the workers cannot memorize, a positional instruction of the parts necessary in the current assembling process will bring the efficiency enhancement of the task as well as comfortable works with less mental stresses. Then we attempt to examine what kind of instruction is effective by the experimental comparison. A visual and/or auditory instruction including its combination will be evaluated as an instructing method.

2. EXPERIMENTAL DESIGN

2.1. Hypothesis

In this paper, we set up the following hypothesis for an assembling task: "If an assembling task is too complicated to remember its process, an explicit positional instruction of the assembling parts brings not only the enhancement of the efficiency but also the comfortability to their operations with less workload." We aim to verify this hypothesis through some comparative experiments of the laboratory assembling tasks. For the explicit positional instruction for the assembling parts, an auditory one, a visual one, and their combinations are relatively examined.

2.2. Consideration of experimental assembling task

The operation time and its workload are going to be evaluated in the experiment. The latter will be obtained by some questionnaires immediately after each assembling task.

All of the parts for the assembling tasks are placed on the fixed position in the workspace. A participant has to search and find a required part in the current assembling process. The unique position is assigned for each part in advance, but its alignment looks surely random for the participant. Some unnecessary parts are also included so that the participant cannot remember the order of the parts. In the experiment, some kinds of product are assembled by putting a designated part in a designated position step by step. Then, some of the parts in

† Satoshi Ito is the presenter of this paper.

Fig. 1 Experimental setups

the workspace have the same shapes but the different colors. The color of parts has no effect to the difficulty of the assembling task since the task complexity depends only on the shape of the parts, not its color. Thus, the variety of parts color in the workspace enables us to maintain the searching difficulty without affecting the assembling difficulty either: the repetitive usage of the same parts allows the participant to remember its position, which reduces the searching time of such parts.

In the experiment, we ask the participant to conduct the assembling process according to the process sheet as quickly and accurately as possible in the specified sequence. Then, for the evaluation of the efficiency, the operation time is counted separately as the searching time and the assembling time.

At the start of each assembling task, all the parts are set up to the same part spaces. In this situation, two conditions of the parts position instruction are examined: a visual instruction that illuminates the space of the required parts, and an auditory instruction that voices the address of each part space.

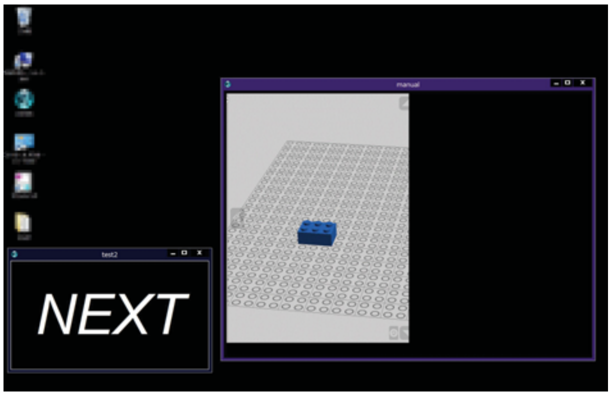
Our hypothesis allows us to expect that the faster finding of the parts improves the work efficiency and reduces the workload. Accordingly, we can predict the followings in this experiment.

- The visual or auditory instruction of the parts position will shorten the searching time.
- Under the instruction where the searching time have been shortened, the assembling time is also shortened.
- Under the instruction where the searching time have been shortened, the workload is also reduced.

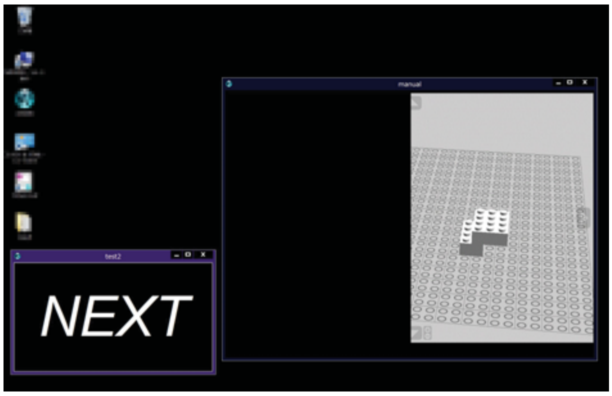
We are going to examine the above three predictions by the experiments.

2.3. Experimental setups and methods

In our experiments, an educational block system (LEGO: Creative Suitcase) is introduced for the assembling tasks from the viewpoint of the safety and the cost. A kind of parts plate is divided into many square parts space and is installed on the fixed position in the workspace. All parts are placed on each square parts



(a) searching phase

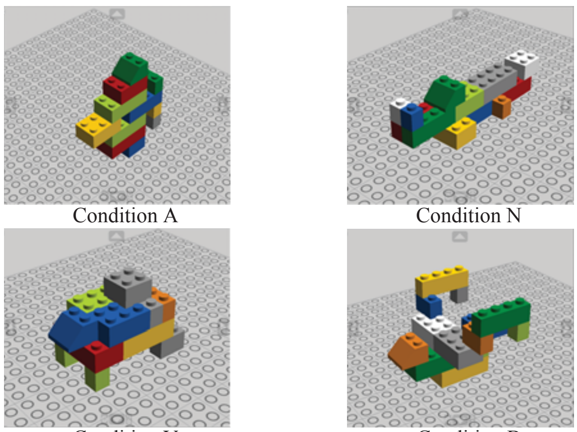


(b) assembling phase

Fig. 2 An electronic process sheet in each task.

space in the fixed order, as shown in Fig. 1. The unique address is assigned to each parts space: From A to J in the vertical, and from 1 to 15 in the horizontal direction. We utilized the flat panel display of the personal computer for pats plate, which enables us to illuminate the parts space independently under the PC control. Namely, the visual instruction utilizes the illumination of the part space with the PC display. On the other hand, the auditory instruction is achieved by automatically calling the address of the parts position using the PC audio speaker.

A participant is asked to assemble the block basically



Condition A Condition N

Condition V Condition B

Fig. 3 Final product of each task.

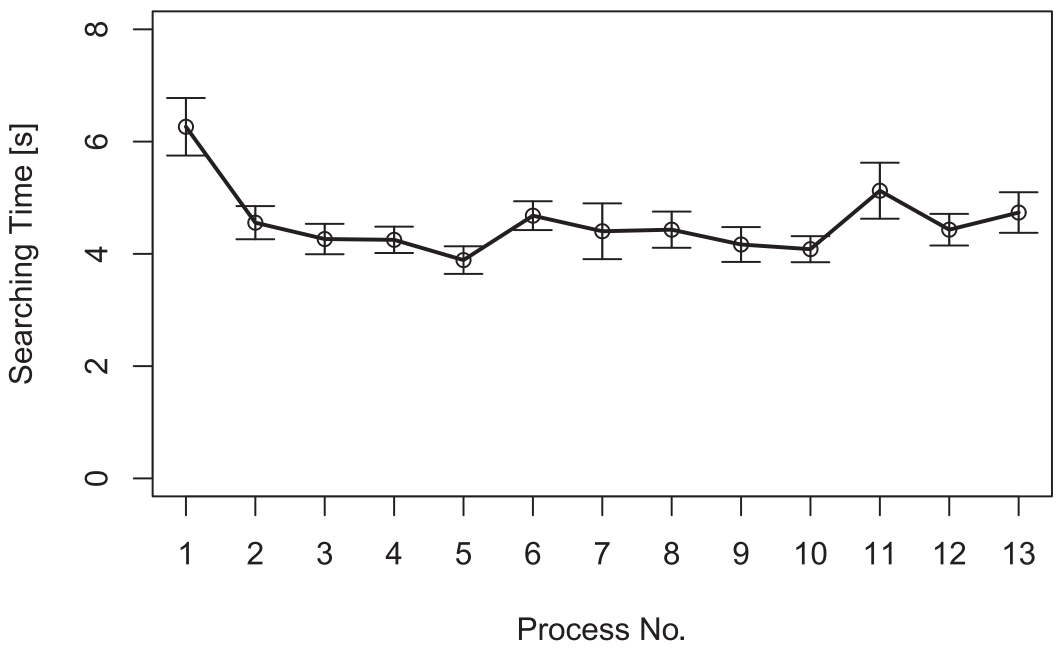


Fig. 4 Searching time with respect to assembly process

according to the electronic process sheet, which is shown in the right bottom of Fig. 1 or Fig. 2. In addition to this electronic process sheet, the visual or auditory instruction of the part position might or might not be given, depending on the experimental conditions.

The task starts with displaying the necessary parts on the electronic process sheet. The participant has to find a part required to 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 kept illuminated as the visual instruction, or the address of this space may be read once as the auditory instruction, depending on the experimental condition. When the participant has found the part, he/she is instructed to pick it up and to 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 comes up in the right column, as depicted in Fig. 2(b). The participant is basically asked to fix the part to the assembling product in the same way as pointed out by this drawing, and then push the 'NEXT' button again when he/she finishes the assembling process. At this moment, the time is recorded as the finish time of the assembling phase, $t_2^{(n)}$, and then one assembling process is terminated. At the same time, the next assembling process gets started by displaying the part required in this process. By the repetition of these processes, the participant has to complete one product.

By regarding the finish time of the assembling phase as the starting time of the next process, the search time $T_s^{(n)}$ and the assembling time $T_a^{(n)}$ are defined as the following equations.

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

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

Immediate after the completion of one product, some questionnaires about the workload are conducted, where six factors are evaluated in ten grades based on the NASA-TLX [4].

The overview of the experimental setups are shown in Fig. 1. Total 126 parts are placed on the parts plate over the flat panel display placed horizontally. Here, we regard the number of the parts as being large enough not to be able to memorize its shape and position. The tablet PC on the table is serving as the processor of the experimental measuring program in addition to the electronic process sheet. This PC is operated with Windows 8.1, the block assemble simulator "LEGO Designer" is used to make electronic process sheet, and the measurement program is developed with script language "Tcl/tk".

2.4. Condition settings

Four conditions are set up for the instruction of the part position: visual instruction only (Condition-V), auditory instruction only (Condition-A), both visual and auditory instructions (Condition-B), and no visual and auditory instructions (Condition-N).

Examining the difference with respect to task difficulties, three tasks are constructed: the task where the participants conducts the assembling as instructed in the process sheet (Task 1), the same task as the task 1 but accompanying the additional adjustments of the block orientation so as to direct the logo on the block to the same

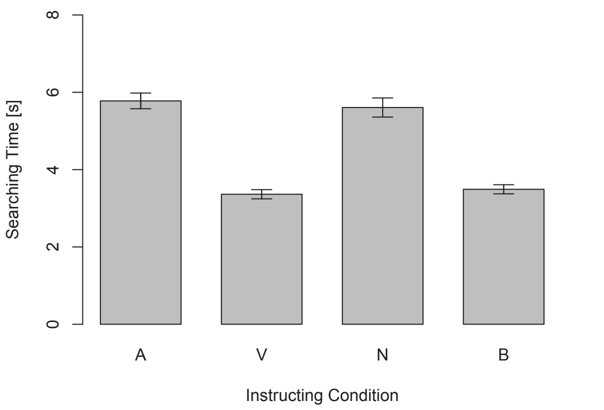


Fig. 5 Searching time vs. instructing condition

Table 1 Tukey's test of searching time against instructing conditions

	V	N	B
Condition A	9.460^{***}	0.670	8.957^{***}
Condition V		8.790^{***}	0.502
Condition N			8.287^{***}

(*:$p < 0.05$, **:$p < 0.01$, ***:$p < 0.001$)

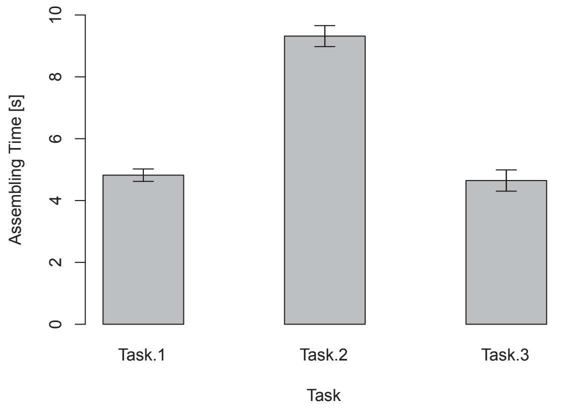


Fig. 6 Assembling time vs. tasks

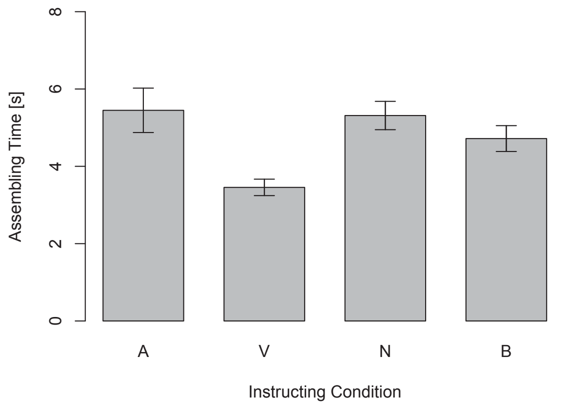


Fig. 7 Assembling time vs. instructing condition

direction (Task 2), and the task in which the participant can assemble the blocks as he/she likes, neglecting the process sheet instruction (Task 3).

The participants have to complete a product under four different conditions for each three different task: total 12 productions in one experiment. The products made up in each condition are shown in Fig. 3. All the products compose of exactly the same 13 parts, in order to remove the effect of the parts difference. The parts with different color are 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 part position.

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

3. RESULTS AND ANALYSES

3.1. Searching time

In this experiment, the number of the parts decreases with progression of the assembling tasks, which may facilitate the finding of the parts unless the sufficient number of the parts remained in the workspace. Thus, the searching time were evaluated in every processes. Fig. 4 shows the searching time in each process averaged over all the tasks, conditions and participants, together with its standard error. Though the searching time at the first process is longer than the others, it does not tend to decrease with progression of the assembling task. It indicates that the sufficient number of the parts are included in this experiment, and thus we can rule out the effects of the decrement of the parts on the searching time according to the task progression.

Next, to investigate the effect of the instructing conditions, the searching time were averaged over the tasks and the participants in each condition. The results are shown in Fig. 5 with standard error. A significant difference were found among four instructing conditions according to ANOVA ($F(3, 15) = 25.001$, $p < 0.001$). Thus, ad hoc analysis was conducted by Tukey's tests. As shown in Table 1, the visual instruction significantly reduced the searching time. On the other hand, the Condition-A with only the auditory instruction seems to have few instructing effects since it did not produce the difference from the Condition-N without instructions.

Finally, ANOVA was applied for the searching time among three tasks. We did not find the significant difference among them ($F(2, 10) = 1.301, p > 0.3$).

3.2. Assembling time

Three tasks were designed to possess the different difficulty. This should be reflected to the assembling time. Fig. 6 shows the assembling time averaged over all the instructing conditions and the participants in each task. ANOVA revealed that the assembling time is signif-

Table 2 Tukey's test of assembly time against instructing conditions after removing Task2

	V	N	B
Condition A	3.578^{**}	0.242	1.311
Condition V		3.336^{**}	2.266
Condition N			1.070

(*:$p < 0.05$, **:$p < 0.01$, ***:$p < 0.001$)

icantly different among three tasks ($F(2, 10) = 12.326$, $p < 0.01$). The following Tukey's tests indicated the assembling time of the Task 2 is different from that of the other two tasks ($p < 0.001$). No differences are found between the Task 1 and the Task 3 ($p > 0.9$).

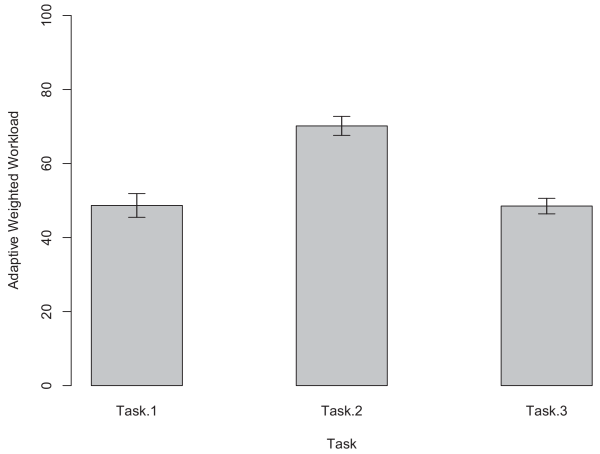
At first glance, the instructing conditions of the parts position might normally seem to have few effects on the assembling time. Actually, ANOVA indicates no significant difference in assembling time with respect to the instructing conditions ($F(3, 15) = 0.484$, $p > 0.69$). However, in the above paragraph, we found that the task 2 largely extends the assembling time in comparison to the other. It may imply that the task 2 would contain another factor, in an additional operation orienting the logo in a single direction, that fatally prolongs the assembling time. Although we intended to distinguish the task by the difficult of the assembly itself, we removed the data of the task 2 in the next assembling time analysis to remove such a factor. The result of this comparison is shown in Fig. 7. Although the significant differences are not obtained from ANOVA ($F(3, 15) = 1.853$, $p = 0.181$), the result of the Tukey's tests in Table 2 indicated that the assembling time is significantly different ($p < 0.01$) between Condition-V and Condition-A as well as between Condition-V and Condition-N.

3.3. Workload

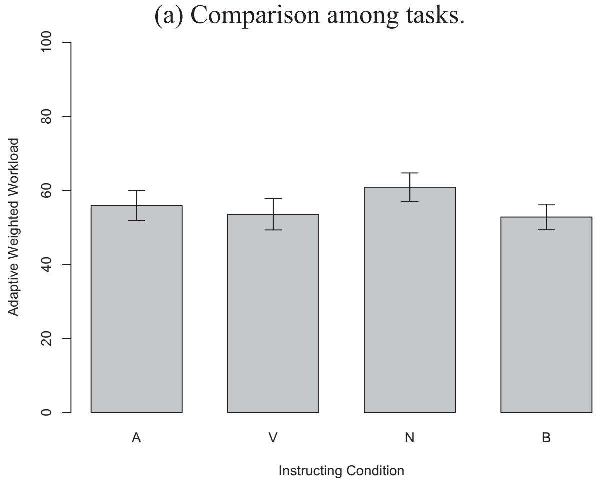
Workloads are evaluated from the adaptive weighted-sum scores of six NASA-TLX questionnaires (AWWL: adaptive weighted workload) immediate after each 12 production [5].

The averaged scores of each task are shown in Fig. 8(a). ANOVA denoted the significant difference ($F(2.10) = 8.090$, $p < 0.01$). The ad hoc analysis, Tukey's tests, indicated that the workload in the Task 2 was significantly large ($p < 0.001$).

On the other hand, the averaged scores of each instructing condition were compared in Fig. 8(b). There are no significant differences among them ($F(3, 15) = 1.641, p > 0.2$), but we can observe that the score with an instruction of the parts position seems smaller than that without instructions. The t-test between the AWWL average scores between Condition-N and the others showed the difference with $p = 0.077$.



(a) Comparison among tasks.



(b) Comparison among instructing conditions.

Fig. 8 Workload evaluation based on NASA-TLX.

4. DISCUSSION

The searching time decreased in both Condition-V and Condition-B where visual instruction is available, in comparison to the Condition-N with electronic process sheet only. However, the Condition-A with only the auditory instruction did not produce the difference in searching time from the Condition-N. Some reasons why the differences appeared between the visual and auditory instructions will be that, the auditory messages were easy to miss hearing, some participants seemed to concentrate the listening rather than the searching of the prime purpose, and the participants could not start searching until the auditory message finished.In this experiment, all the parts were placed at a relatively narrow area that the participants could watch all in one eyeshot. In such a case, the participants did not have to move the line of the sight. If he/she have to switch their gaze, the auditory instruction such as beep sounds from the parts direction will come to be effective. Thus, this result will depend on the experimental protocol. Anyway, we can say that, in this experiment, the visual instruction of the parts position was more effective.

Next, let us discuss the assembling time. In our first prediction, the assembling time was expected to show the difference with respect to the instructing conditions whether task difficulty was the same or not. However, overall analysis not discriminating three kinds of tasks indicated no significant differences among four instructing conditions. Thus, we restricted the range of the analysis to Task 1 and Task 3 only, which have no differences in the assembling time. As a result, the assembling time with the visual instruction only was significantly shorter than that without it. The Task 2 includes an operation uniforming the logo direction, which may enhance the difficulty of the task from another point of view than the assembling itself, and produce the larger differences among participants. In the Condition-V and the Condition-B where the searching time had decreased, the assembling time also reduced. Especially, in the Condition-V, it was shortened significantly. From these facts, we can infer that the reduction of the searching time brings the enhancement of the efficiency, i.e., the shortness of the assembling time.

Finally, regarding the workload, significant differences were not detected among the instructing conditions. However, a sort of positional instruction tends to decrease the workload. The positional instruction may have an small good effect to all the tasks from the viewpoint of workload reduction, without limiting to the task in which the searching and assembling time was reduced.

In summary, we confirmed some results for our first and second predictions in section 2.2, that is, in an assembling task using many parts, the visual instruction of the parts position shortened not only the searching time but also the assembling time. However, the workload evaluated by NASA-TLX was not much affected by the instructions, but it did tend to increase without any instructions. Some investigations will be required to evaluate our third prediction.

5. CONCLUDING REMARKS

In this paper, we discussed an effectiveness of the parts position instruction, in a situation where the number of the parts are too large to remember its storage location. We designed a method of the laboratory experiment to examine our hypothesis, "an instruction of the parts position enhances the efficiency and reduces the workload." In this experiment, the assembling task of the educational block was introduced as feasible tasks in the laboratory environment. These tasks were applied to evaluate how a visual instruction illuminating the parts space and/or an auditory instruction announcing the address of the parts space affect on the searching time, the assembling time and the workload assessed with NASA-TLX, by testing six participants. As the results, we confirmed the following facts in our experimental environment.

- An introduction of the visual instruction of the parts position shortens the searching time.
- In a condition with the visual instruction only where the searching time has decreased, the assembling time is also reduced significantly.
- In conditions with a kind of instruction, the workload tended to decrease, but it was not significant

Based on these facts, we can conclude that our hypothesis is partially validated. In the future works, we attempt to evaluate the workload in relation to the bio-signals, and discuss the relationship among the task instruction, performance and mental-load.

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