Development of Survey Tools for Indoor Environmental Quality and Productivity

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SUMMARY

A computer program for both field survey and laboratory experiment was developed to evaluate performance of office works and to link the findings from experiments to the actual offices. The program has three parts: namely, Voting Tool, Task Tool, and Performance Evaluation Tool. In this study, the Performance Evaluation Tool, which is consisted of twelve standard tests, was examined. The abilities required for the office works in two companies and one branch of the government office were collected to verify the applicability of the Performance Evaluation Tool. Two subjective experiments were conducted to determine the abilities required to work on each of twelve tests and to examine the reliability as a measurement tool for performance. From the results, there were some abilities required in offices but not for the tests, and the need for further modification was addressed. The performances of the tests were positively correlated with that of multiplication task (r=0.86).

INTRODUCTION

Performance is essential for the evaluation of productivity. Unfortunately, the performance of office works is mostly hard to quantify. To evaluate the effect of indoor environmental quality on performance quantitatively, mental tasks, such as three-digit multiplication, text-typing, and memorization of letters, have been assigned in the subjective experiments [1][2][3][4]. However, there is no guarantee that those simulated tasks are good representations of actual office works. Also, the importance of evaluation of human responses, such as fatigue, cerebral blood flow, sensation to the environment, was reported from the results of short-term experiments [5][6]. The survey tools developed in this study were to equip the quantitative measurement method of performance with the appropriate relationship to the performance of office works and the measurement method of human responses as used in the previous studies. The main purposes of this paper were to introduce this survey tools and to examine the characteristics and practicality of the Performance Evaluation Tool, which was developed as a part of the survey tools to measure performance quantitatively in both field surveys and laboratory experiments.

METHODS

First, a summary of the survey tools was briefly described and the tests of the Performance Evaluation Tool were introduced. Then, the questionnaire form was described with the categories of cognitive abilities, which were used to relate the Performance Evaluation Tool to tasks and office works. Also, the methods of this study, which includes questionnaire surveys on two companies and one branch of the government office and two subjective experiments, were explained.
Survey Tools for Indoor Environmental Quality and Productivity

PC-based survey tools were developed to evaluate the effect of indoor environmental quality on productivity. The tools are programmed as computer software with a mouse and a numeric keypad to respond. The tools include three types of evaluation tools, which include Voting Tool (V-Tool), Task Tool (T-Tool) and Performance Evaluation Tool (P-Tool). V-Tool is consisted of questionnaire forms including: votes on environment, Evaluation of Subjective Symptoms of Fatigue [7], and NASA-TLX [8], to evaluate human responses and fatigue. T-Tool is a set of experimental assignments such as multiplication tasks. P-Tool contains twelve standard tests as described in the next section.

Performance Evaluation Tool

P-Tool was developed to evaluate objectively the performance level of the persons in both field survey and laboratory experiment. The P-Tool was also rebuilt as web-based programs for the field surveys, because it has recently been difficult to directly install personally-built programs into the computers in offices for the security reasons. The P-Tool was installed into the PCs of the laboratory and was run without internet access in this study. It is consisted of twelve standard tests programmed with references from the Walter Reed Battery Tests [9] and examples given in the literature [10]. The twelve tests are:

(I) Manikin – a manikin surrounded by circle or square carries circle and square on his hand appears on the screen. Subjects are to answer the side of hand that carries same or different shape compared to the shape surrounds manikin;

(II) Coordinate – based on the table of numbers with corresponding alphabets, subjects are to choose the coordinate point that are implied by the randomly selected combination of two alphabets;

(III) Coding - based on the table of numbers with corresponding alphabets, subjects are to input a number that is implied by a randomly selected alphabet letter;

(IV) Four choice – a panel with 1,2,4,5, corresponding to a portion of numeric keypad, is appeared with background color of one number is highlighted. Subjects are to input the highlighted number;

(V) Nine choice – similar to the Four choice but the panel with numbers from 1 to 9;

(VI) Time-lag input – subjects are to input the number that is appeared previously;

(VII) Arithmetic symbol – subjects are to answer the correct arithmetic symbol to complete the equation; appeared on the screen

(VIII) Positioning – subjects are to select the number as instructed from the randomly positioned 25 numbers appear on the screen;

(IX) Pattern memory – subjects are to answer whether randomly positioned dots appear twice are the same or different;

(X) Letter search – from the thirteen alphabet letters, subjects are to answer whether the target two letters are included both, only one, or neither;

(XI) Classification rule – subjects are to answer the rule that classifies the boxes with □ ■ ▲ ○ ● as appeared; and

(XII) Pattern search – target pattern of sixteen mosaics with alternatives were shown. Subjects are to select the same pattern from the alternatives.

Cognitive abilities

In this study, the abilities required for the office works and P-Tool were in focus. The ability classification questionnaire was used in the questionnaire surveys and in the Subjective Experiment 1. The abilities and its definitions were cited from the Cognitive Abilities proposed by Fleishman [10]. The abilities include: (1) Oral comprehension; (2) Written comprehension; (3) Oral expression; (4) Written expression; (5) Fluency of ideas; (6) Originality; (7) Memorization; (8) Problem sensitivity; (9) Mathematical reasoning; (10)
Number facility; (11) Deductive reasoning; (12) Inductive reasoning; (13) Information ordering; (14) Category flexibility; (15) Speed of closure; (16) Flexibility of closure; (17) Spatial orientation; (18) Visualization; (19) Perceptual speed; (20) Selective attention; and (21) Time sharing. The abilities required to the subjects or workers for their works were marked with the ability classification questionnaire, which is shown in Figure 1.

| Q1. Briefly explain the type of your work _______________________________. |
| Q2. Mark in the left box of the following abilities that are required for your work. |
| Ability to understand spoken (English) words and sentences |
| Ability to understand written sentences and paragraphs |
| Ability to use (English) words or sentences in speaking so others can understand |
| Ability to use (English) words or sentences in writing so others can understand |
| Ability to produce a number of ideas about a given topic |
| Ability to produce unusual or clever ideas about a given topic or situation |
| Ability to remember information, such as words, numbers, pictures, and procedures |
| Ability to know when something is wrong or is likely to go wrong |
| Ability understand and organize a problem and then to select a mathematical method or formula to solve the problem |
| Ability to add, subtract, multiply, divide, and manipulate numbers quickly and accurately |
| Ability to apply general rules to specific problems and to come up with logical answers |
| Ability to combine separate pieces of information, or specific answers to non-mathematical problems, or to form general rules or conclusions |
| Ability to correctly follow a rule or set of rules specifying how to arrange things or actions in a certain order |
| Ability to produce many rules in such a way that each rule tells how to group a set of things in a different way |
| Ability to quickly make sense of information which initially seems to be without meaning or organization |
| Ability to identify or detect a known pattern (e.g., a figure, word, or object) that is hidden in other material |
| Ability to know one’s location in relation to the environment one is in or to know where an object is in relation to oneself |
| Ability to imagine how something will look when it is moved around or when its parts are moved or rearranged |
| Ability to compare letters, numbers, objects, pictures, or patterns, quickly and accurately |
| Ability to concentrate on a task over a period of time |
| Ability to shift back and forth efficiently between two or more activities or sources of information |

Figure 1. The ability classification questionnaire

**Questionnaire surveys**
To obtain the balance of abilities of the office works, the ability classification questionnaire had been collected in Company M, Company T and one branch of the government office. In Company M, 75 workers were surveyed; of 69 took over clerical job, of 3 took over technical job and of 3 had no response. In Company T, 50 workers were surveyed; of 46 took over technical job and of 4 took over clerical job. In the government office, 76 workers were surveyed; of 66 took over clerical job and of 10 took over technical job.

**Subjective Experiment 1**
The purposes of the experiment were to gather information to modify the operationality of P-Tool and to understand the characteristics of P-Tool by obtaining the abilities required for each test. Thirty-one college-aged subjects, eight female and twenty three male, participated in the experiment. Subjects wore their own clothes and were allowed to adjust their clothes during the experiment. The experiment was conducted on July 26-28, 2006 in a climatic chamber and the waiting room. The layout of the chamber with the waiting room and a
picture during the experiment were shown in Figure 2. Two subjects were paired and participated only once in this experiment. The physical environment for the climate chamber was measured with IAQ monitor for air temperature, relative humidity, the concentration of CO₂, and noise meter for sound level. The conditions of the climatic chamber were as follows: average air temperature was 25.4°C with standard deviation of 0.1°C; average relative humidity was 50% with standard deviation of 0%; the concentration of CO₂ was 576ppm with standard deviation of 55pppm; and equivalent sound level was 56dBA.

Figure 2. (a) The layout of the climatic chamber and the waiting room; and (b) a picture during the Subjective Experiment 1 in the climatic chamber.

Procedure of the experiment is shown in Figure 3. In the waiting room, instructions and procedures of the experiment were given to the subjects first, and the subjects worked on each test of P-Tool for 1.5 min and then reported on the evaluation sheets on the test. After all twelve tools were finished; subjects moved into the climatic chamber and reported the Evaluation of Subjective Symptoms of Fatigue. They again worked on each test of P-Tool for 3 min and then reported the ability classification questionnaire on the test. After all twelve tests were finished, subjects reported the Evaluation of Subjective Symptoms of Fatigue.

Subjective Experiment 2
Another subjective experiment was conducted to evaluate the compositive effect of thermal environment and indoor air quality. From the perspective of evaluating the P-Tool, this experiment was conducted to examine the relationship between the performance of the P-Tool and multiplication task. The experiment was conducted in the climatic chamber as shown in Figure 4 with twelve male subjects from September 18 to October 19, 2006. Three subjects were participated together in this experiment. Subjects wore shirt with long sleeves and pants (0.66clo) [11] during the experiment. A practice and four experimental conditions were set: A) Practice with operative temperature of 28.5°C and Low ventilation rate; B) 28.5°C-Low ventilation rate; C) 28.5°C-High; D) 25.5°C-Low; E) 25.5°C-High. Subjects experienced
Practice first and then these four conditions in balanced order. They were exposed on the same time of the day in the successive weeks to avoid the influence of time. The tests of P-Tool used in this experiment were selected based on the results of the Subjective Experiment 1. Because one subject had fever in one of the conditions, his data was excluded for the analysis, i.e. data from eleven subjects were used for analysis in this experiment.

Figure 4. (a) The layout of the chamber; and (b) a picture during the Subjective Experiment 2

The procedure of the experiment is shown in Figure 5. In the waiting room, subjects changed their clothes, instructions were given, and they rested in sedentary position for ten minutes. Then, the subjects moved into the chamber, reported on the environment and the Evaluation of Subjective Symptoms of Fatigue, and worked on P-Tool. After resting in sedentary position for thirty minutes, subjects voted on the environment, reported the Evaluation of Subjective Symptoms of Fatigue, and worked on P-Tool. Then six sessions of multiplication task with votes and P-Tool between the tasks were assigned to the subjects. After the sessions, they reported the predicted-performance-vote [12] at the end of the experiment.

![Diagram of experiment procedure](https://via.placeholder.com/150)

Figure 5. Procedure of the Subjective Experiment 2.

RESULTS

Questionnaire surveys

The results of ability classification questionnaires were shown in Figure 6. Abilities were evaluated by the fraction of the number of workers who responded the ability to be required to the number of total workers. In these offices, (1) Oral comprehension, (2) Written comprehension, (3) Oral expression, and (4) Written expression were the abilities that were evaluated as "required" by over 85% of workers. The abilities such as (6) Originality, (11) Deductive reasoning, (12) Inductive reasoning, (14) Category flexibility, (16) Flexibility of closure, were required in Company T, in which most of workers took over technical jobs unlike the other two. The ability classification questionnaire can be a useful method for understanding the characteristics of the office.
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Figure 7. Results of abilities classification questionnaire of each test of the Performance Evaluation Tool. The numbers in parenthesis in the figures correspond to the abilities described in the section “Cognitive abilities”.

Subjective Experiment 1
The balance of the abilities required to work on each test are shown in Figure 7. (19) Perceptual speed and (20) Selective attention were the abilities that were highly required in all of the tests. Other than the two, the balance of the abilities required differed from test to test. There were some tests, however, that were similar in terms of required abilities. For the practical use in future researches, six tests were selected keeping the new set of tests to have similar balance of required abilities as a total. The selected six tests, together called P-Tools, were: (I) Manikin; (II) Coordinate; (IV) Four Choice; (VII) Arithmetic symbol; (XI) Classification rule; and (XII) Pattern search.

Figure 6. Results of ability classification questionnaire at (a) Company M, n=75; (b) Company T, n=50; and (c) government office, n=76. The numbers in parenthesis in the figures correspond to the abilities described in the section “Cognitive abilities”.

(a) Company M  
(b) Company T  
(c) government office
Subjective Experiment 2

To examine the reliability of the P-Tool, it was compared with the multiplication task. The results of ability questionnaire survey for the P-Tool from the Subjective Experiment 1 and that for the multiplication task are shown in Figure 8. The balance of the abilities required for the P-Tool covered that for multiplication task.

Figure 8. Results of ability classification questionnaire for (a) P-Tool and (b) multiplication task. The numbers in parenthesis in the figures correspond to the abilities described in the section “Cognitive abilities”.

Performances of both the P-Tool and multiplication task were normalized to exclude individual variability by obtaining z-scores for each subject. The data set of performance of the P-Tool with interval of 0.5 in z-score was averaged and corresponding performance of the multiplication task was averaged. The relationship between the two performances is shown in Figure 9 with a linear regression model weighted by the number of subjects. It was positively correlated with the correlation coefficient of 0.86. The result gave some proof on the adequacy of the P-Tool as a measurement method of the workers’ performance indirectly.

Figure 9. The relationship between normalized performance of the multiplication task and of the P-Tool, and a linear regression model weighted by the number of subjects.

DISCUSSION

Cognitive abilities required in offices and in the Performance Evaluation Tool

From the results of ability classification questionnaire in offices and Subjective Experiment 1, there are some differences in the abilities required between office works and the P-Tool. For office works, major abilities required were of (1) Oral comprehension, (2) Written comprehension, (3) Oral expression, and (4) Written expression, which were not evaluated as much for the P-Tool. Some of the methods to test these abilities have been introduced in the previous works [10]. However, they are not suitable for repetative use, for scoring objectively and automatically, to avoid uniformality of the difficulty of each question, etc., that are not negligible when the use in offices is assumed. Further modification of the P-Tool for these abilities may be needed.
Performance Evaluation Tool as measurement of performance

From the results of Subjective Experiment 2, the performance of the P-Tool was correlated well with the performance of multiplication task. There would be still some more studies needed on the tasks other than multiplication for conclusive evidences to convince that the P-Tool can be applied in the situation where direct performance is difficult to quantify. Also, the web-based version of the P-Tool needed to be practiced in the field.

CONCLUSION

In this paper, the survey tools for indoor environmental quality and productivity were introduced, and the characteristics and practicality of the Performance Evaluation Tool were examined.
1) The results from survey and experiment, there were some abilities required in offices but not for the tests, and the need for further modification was addressed.
2) The balance of the abilities required for the Performance Evaluation Tool covered that for multiplication task. The performance of the Performance Evaluation Tool was positively correlated with the performance of multiplication task.

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