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# IMPLICATIONS FOR MAN-MACHINE INTERFACE DESIGNING FROM THE FINDINGS OF BASIC LABORATORY EXPERIMENTS ON HUMAN COGNITIVES

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ABSTRACT

Using eye mark recorder and polygraph, basic laboratory experiments have been conducted to investigate the validity of psycho-physiological measures to the analysis of on-line cognitive information characteristics at man-machine interface (MMI). It is concluded that various psycho-physiological measures are useful to estimate various aspects of human cognitive characteristics and thus to the evaluation of MMI designing from the viewpoint of its harmony to the human cognitives.

## 1.INTRODUCTION

With regards to safe and reliable operation of complex, large-scale modern technical systems as a viewpoint of man-machine system, it is important to understand human cognitive characteristics at man-machine interface (MMI). The relevant cognitive process is understood as "on-line event-driven" information processing, where the man at MMI maniputes in his brain, his perceived "out-world" information and two types of pre-acquired knowledge (mental model): (i) static model on system structure and function of the plant to be controlled, and (ii) dynamic model to predict event transition in the plant process and to select appropriate control actions. The potential source of human error in plant operation lies in the (A) structure and contents of the perceived out-world information and the two mental models, and (B) their manipulation process. Therefore, it is important to understand the relevant characteristics of human cognitives, and to reflect them to the MMI designing. But since human cognitives are mental process, it is a rather difficult problem to construct objective methodology of measuring and analyzing the related characteristics. The authors conducted basic laboratory experiments on human cognitives by using eye mark recorder and polygraph, and tried to reduce various human cognitive characteristics which are required for MMI designing.

## 2.FRAMEWORK OF EXPERIMENTAL STUDY

### 2.1 Underling Theory

As a model of human information behavior at MMI, we adopted a conceptual scheme as shown in Fig.2.1, by simplifying Rasmussen's multi-ladder decision model [1] and considering the data factors on observation. We then considered various aspects of human cognitive characteristics at each "concrete state" which is the manifestation of internal circulations of "observation identification - interpretation - evaluation planning", and then we classified those characteristics into the three categories: (i) basic functions of human information processing, (ii) performance measures of the human cognitive process which is the integration

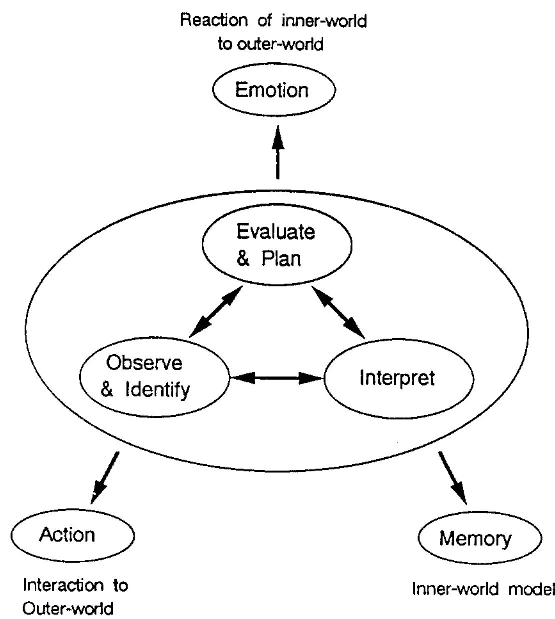


Fig.2.1 Conceptual model of human information processing.

and co-ordination of the basic functions, and (iii) psycho-physiological factors which affect the above co-ordination process. Fig.2.2 shows the characteristic items we have been investigating from the aspect of human-centered MMI designing.

## 2.2 Experimental Method

We will summarily describe the experimental environment we utilizes in our experimental

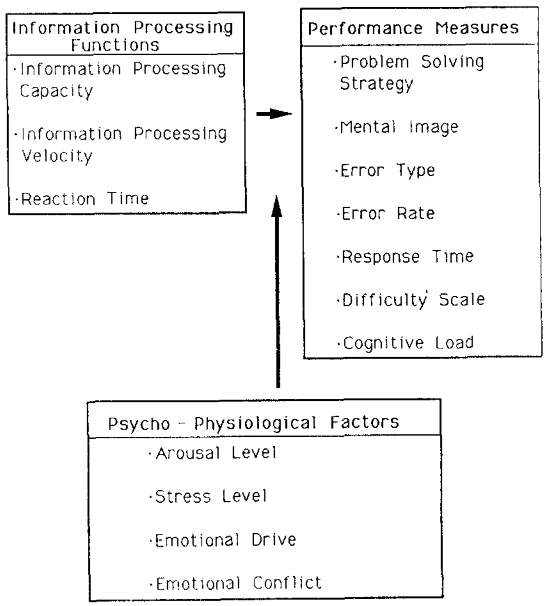


Fig.2.2 Observed characteristics of human information processing.

study. Firstly, personal computer-based experiment system is used to "present various cognitive tasks to the subjects through video display terminal (VDT) or voice communication unit (VCU), (ii) to record eye mark recorder data, polygraph data, and verbal protocol data from the subjects participated in the experiments and (iii) to record subjects' interactive response to personal computer.

Types of cognitive tasks presented to the subjects were related with memorization, pattern recognition and mental calculation. Those tasks were selected as basic elements of cognitive tasks at MMI.

There are two types of experiment. One is the experiment with a single subject and the other, competitive experiment by two subjects. The reason why competitive experiment is because the subject would participate in the experiment more positively than alone and that more stressful situation would be implemented than by a single subject participation.

Concerning the measured data items, eye mark trajectory and eye pupil size were measured by eye mark recorder, while various physio-electric signals such as ECG, skin potential response, EEG and respiration curve were measured by polygraph. The reason why those psycho-physiological data were selected in our experiment is because, first of all, eye mark trajectory would well reflect subject's visual information search at MMI, and the rest of data, pupil size and most of physio-electric signals, are governed by autonomous nerve system and they

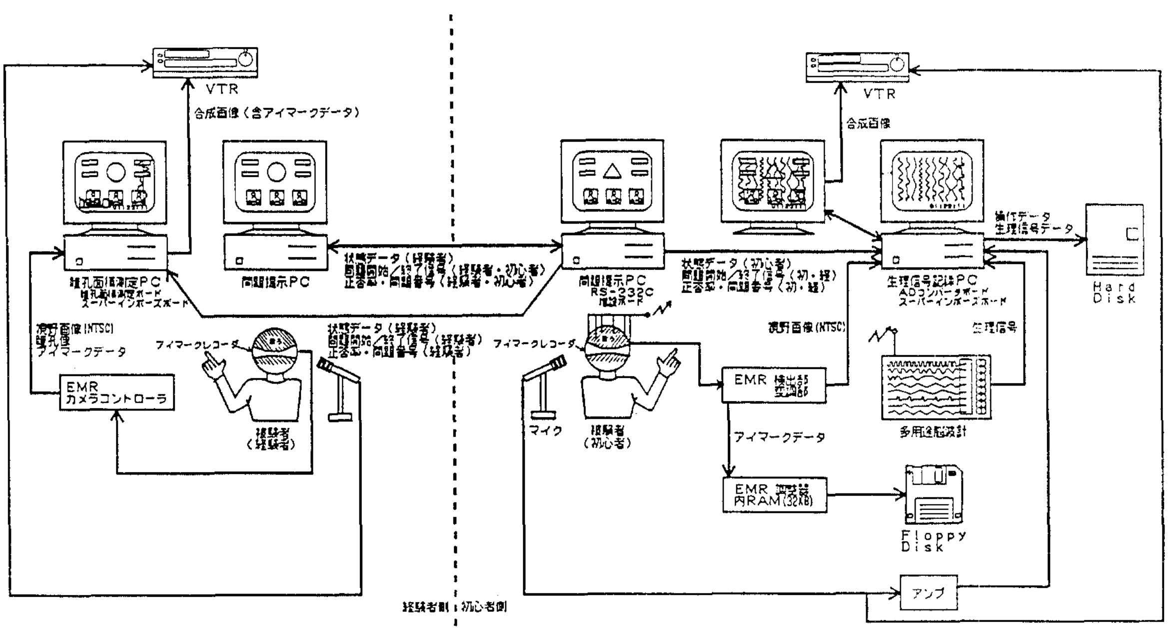


Fig.2.3 Example of experimental system setup (competitive experiment by two subjects).

are said to fluctuate unconsciously well enough to reflect subject's mental situations [2]. Fig.2.3 shown an example of our experimental system setup for complicated case of competition experiment by two subjects.

### 2.3 Analysis Method

Concerning the analysis and interpretation of the protocol data, a "holistic" approach is needed to understand the subject's cognitive behavior. From this aspect, the recorded data taken from the subject during the experiment were processed by using personal computer and work station to obtain a "time line chart" as shown in Fig.2.4. The time line chart shows the time trends of various psycho-physiological data, sequence of his think-aloud protocol, and the record of his interaction to VDT, on the same time axis from the beginning of problem solving. We mainly utilized the time line chart to analyze, interpret the subject's process of problem solving, and to obtain insights to derive various cognitive characteristics as listed in Fig.2.2.

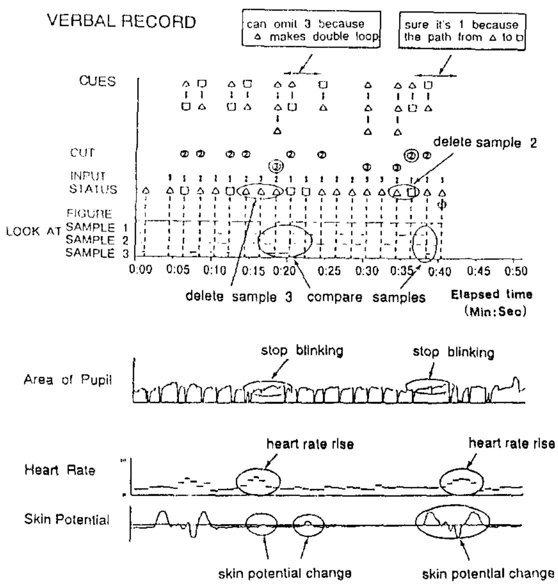


Fig.2.4 Example of time line chart (subject HY, Exp.2).

## 3. INVESTIGATION ON APPLICABILITY OF PSYCHO-PHYSIOLOGICAL MEASUREMENT

### 3.1 Example of Experimental Analysis

In this section, an example of experimental analysis will be described how we interpreted the psycho-physiological data taken from a single subject HY (student, male) with respect of his cognitive load and the asynchronization to the external information change.

Description of experiment

The material of the cognitive tasks for the subject is three-input-three-state transition model as shown in Fig.3.1. There are three states of circle, triangle and square figure, and the state will change according to the input keys 1, 2 or 3 with the direction of arrow lines indicated by the graph.

There are three experiments (see Fig.3.2). Experiment 1 concerns memorization, and experiments 2 and 3, classification. Fig.3.2 shows the essential point of CRT display for those experiments. In experiment 1, the subject is asked to understand the hidden state transition model by his own trial of pushing keys and seeing the change of figure on screen

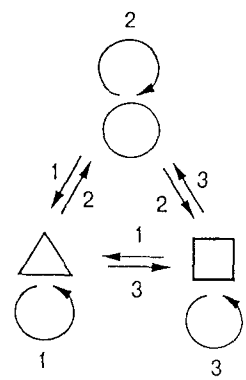


Fig.3.1 State transition model used for cognitive tasks.

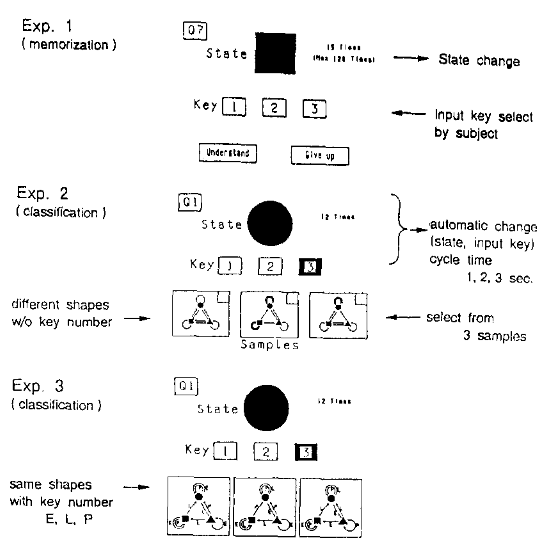


Fig.3.2 CRT display for cognitive tasks on memorization and classification.

many times until he can report all the rules of the state transition model. The memorization quantity of the model is 3 input keys x 3 figures = 9 rules with 3 items (key, from, to) per one rule. This is more than magical number (7 chunks ±2) of human working memory [3]. In case of experiments 2 and 3, the input key and state on the screen changes automatically in random fashion with every 1 or 2 or 3 seconds according to the hidden model. The subject is asked to select which one of the three samples below is the right one. The difference of the both experiments is the way of presenting the three samples below. In experiment 2, the shapes of the three samples are different with each other with no indication of input key numbers. But in experiment 3, the shapes of the three samples are the same one with input key difference shown by different letters E, L and P. The experiment 3 is more difficult than experiment 2. In every experiment of 1, 2 and 3, there are more than 33 tests of different problem in succession.

Interpretation of cognitive load by heart rate

The result of the subject's average heart rate changes is shown in Fig.3.3, with the progression of test numbers in each experiment. As seen from the figure, the heart rate in experiment 1 decreased with the progression of test numbers, while in experiments 2 and 3, there are no such tendency but almost flat. This result is interpreted like the following. The gradual decrease of his heart rate in experiment 1 is ascribed to the gradual familialization so that his problem solving method becomes fixed with the accumulation of test numbers because he can control the problem solving by his own will. But there were no such familiarization in experiments 2 and 3 because the information is always given to him automatically from the computer in unexpectable manner, and so the situation was probably always new to him at every test.

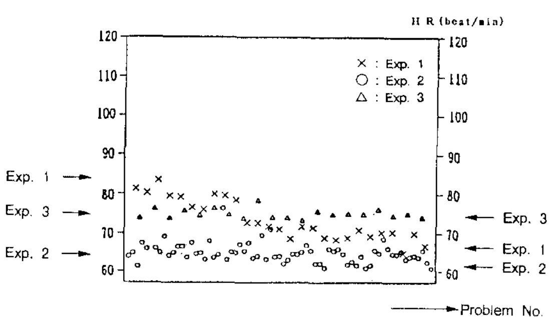


Fig.3.3 Time trend of average heart rate with the progression of test numbers (subject HY).

Another observation from Fig.3.3 is that the difference of the heart rate levels among the three experiments are ascribed to the difference of the cognitive load. That is, in the beginning phase, the problem is difficult for him with the order of experiment 1, 3, 2, while in the later phase, experiment 3, 1, 2.

Interpretation of asynchronization to external information change by blinking data

The statistical distribution of his blinking interval are plotted in Fig.3.4 for the three experiments. At experiment 1, since the subject can control the problem solving by his own timing, this shape of distribution would be interpreted as his natural blinking habit in thinking. But looking to the distribution shapes of experiments 2 and 3, you can see peaks at 1, 2 and 3 seconds which are the external information cycles for those experiments. This means his blinking synchronizes the external information cycles. We look into the experiment 2 further for the information cycle changes.

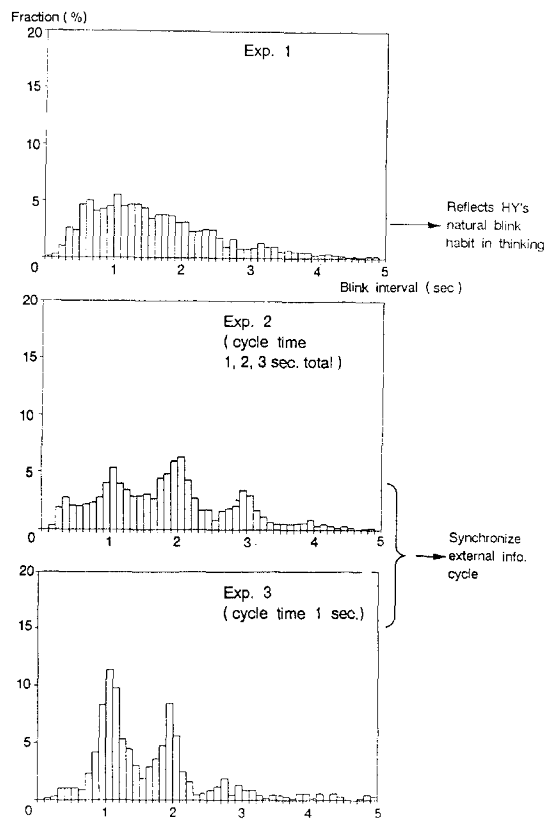


Fig.3.4 Statistical distributions of blinking interval (experiments 1, 2 and 3).

Fig.3.5 shows the distribution shapes of time cycle 3, 2 and 1 second, respectively. In case of 3 seconds, you can see that his blinking habit reappears in addition to the sharp peak at 3 seconds. This means that if the information change is as slow as 3 seconds, he has enough time to think. But in the rapid case of 1 second, you can see peaks at 1, 2 and 3 seconds with the 2 seconds case the biggest one. This suggests that 1 second information change is too fast for him to follow. We made an independent study of clue missing rate and clue detection rate for those three cases by the detailed analysis of his time line chart, and the result is listed in Table 3.1. By this table, we estimated that the information change of 2 seconds is the admissible limit to external information change for him. And again from the figure of 2 second case in Fig.3.5, the biggest peak is at 2 seconds with a slight reappearance of natural thinking habit.

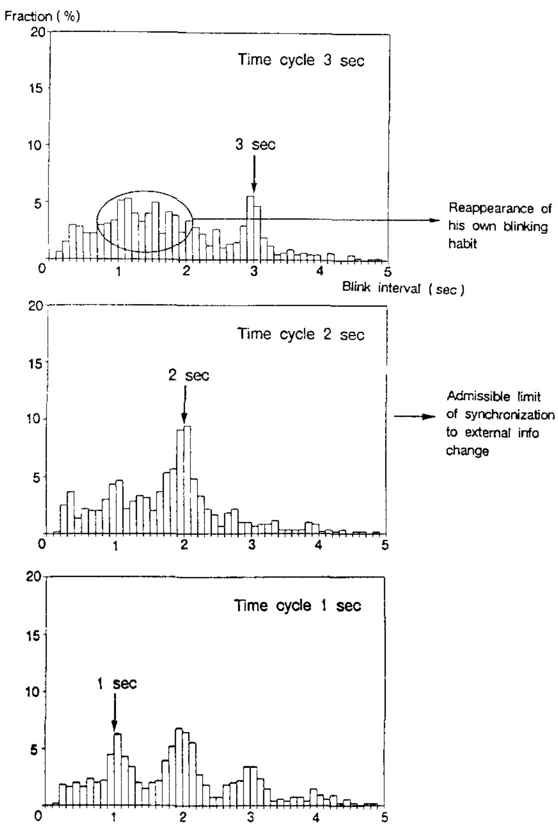


Fig.3.5 Statistical distribution of blinking interval (time cycle 1, 2 and 3 seconds, experiment 2).

3.2 Implication to the Evaluation of MMI-Designing

By the similar way as in described in 3.1, we investigated the effectiveness of various psycho-physiological measures by eye mark recorder and polygraph with respect to the cognitive characteristics listed in Fig.2.1. The summaries of the investigation are shown in Tables 3.2 and 3.3, for the meaningful measures by eye mark recorder and polygraph, respectively.

Table 3.1 Effect of information cycle to performance (subject HY, experiment 2).

| Time cycle (second) | Missing rate of clue occurance | Rate of clue detection |
|---|---|---|
| 1 | 0.475 | 0.477 |
| 2 | 0.190 | 0.644 |
| 3 | 0.129 | 0.609 |

Measures by eye mark recorder

Saccade fraction is a good measure of subject's visual information search type whether or not he has to look many different places on a screen display to perform a specific cognitive task at MMI.

Statistics of eye fixation time reflects his effort level of thinking, while from the statistics of blinking interval, we can estimate his asynchronization to the external information cycles presented at MMI.

Rapid change of pupil size, whether it grows large or shrinks, is caused by many psychological factors listed in Table 3.2.

Table 3.2 Psycho-physiological measures by eye mark recorder and their cognitive characteristics.

| Measures | Related Cognitive Characteristics |
|---|---|
| Saccade fraction | Type of visual information search |
| Distribution function of eye fixation time | Level of thinking ( cognitive load ) |
| Distribution function of blinking interval | Asynchronization to external information cycle |
| Rapid change of pupil size | |
| up: | Clue finding |
| down: | Attention, memory search |

Measures by polygraph

Skin potential response is a good measure of identifying the subject's emotional drive caused by many situations listed in Table 3.3.

Concerning heart rate, if we look to its instantaneous change, there is a tendency that upward change would be brought about by cognitive effect such as clue finding, while downward change would be caused by attention to external information. And if we look to the average heart rate level for the whole time span of problem solving, then it is a good measure of estimating cognitive load or stress level to solve the problem.

As far as EEG is concerned, we have not yet examined it so much, but we only confirmed that high fraction of alpha wave is the measure of identifying arousal decline.

Table 3.3 Psycho-physiological measures by polygraph and their cognitive characteristics.

| Measures | Related Cognitive Characteristics |
|---|---|
| Skin potential response | Change of intent, clue finding, memory search, etc. |
| Heart rate | |
| instantaneous | |
| up : | Clue finding |
| down : | Attention to external info. |
| average | Cognitive load, stress |
| EEG | |
| $\alpha$-wave level up : | Arousal decline ( low attention) |

## 4.CONCLUSION

With the purpose of developing objective analysis methodology of cognitive factors at MMI, the authors have conducted various basic laboratory experiments to investigate human cognitive characteristics. Eye mark recorder and polygraph were utilized to obtain psycho-physiological data from the subject, together with the verbal report. The general observation from the experiments is that human tends to take problem solving strategy with cognitive load as low as possible and that there is a limitation of cognitive information processing speed for each task. Mental image to the problem is a critical factor to improve performance. We believe that the bio-informatic measurement as presented in this paper would be a useful method of evaluating MMI designing from the viewpoint of harmony between human and computer.

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