

Development of experimental system of human function for reliability-based design

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In order to evaluate the human reliability, a new experimental paradigm is introduced for the measurement of the human function by psychophysical method and physiological signals. The feature of the proposed experimental paradigm is to be able to obtain the human function by psychophysical quantities such as the region of detectable field of view and physiological signal such as EEG at the same time. Two kinds of experiments were carried out. One is to measure the region of the useful field that is the region to detect a simple white circle as a target mark. The other is to measure the region of the useful field that is the region to be able to recognize a specified shape among the similar marks.

Key words: Human reliability analysis (HRA), Psychophysical method, Physiological signals.

1. Introduction

The theory for reliability-based design has advanced considerably in the last thirty years and has found many applications to design standards and procedures. Through the improved understanding of the risk of structural

failure that it provides, it has become possible to achieve more optimal investment in that part of structural safety that is effectively controlled by the traditional safety factors. However, a considerable discrepancy has been observed between the theoretical and practical failure rates. This discrepancy is due to an incomplete theoretical model. Most of the failures of structural system occur due to human errors which are not included in the analysis [1].

The major factor of uncertainties in evaluation of structural performance is derived from human error. Therefore, the analysis of human errors provides useful information required for the advance of an efficient management of structural safety, since structural failures are due mostly to omissions, misunderstanding, abuse and fraud. A lot of models of HRA (Human Reliability Analysis) have been proposed until now from the widespread fields such as psychological observation, natural science tradition, behaviour or social science tradition and cognitive science tradition [2-4]. However, the need for the models can be made clearer if a distinction is made between different instances of the models. For example, the primary purpose of the scientific model is to aid understanding of a phenomenon, on the other hand that of the engineering model is to develop a representation of a system which can be used to calculate or forecast future development [3].

As a role of playing the bridge among these models, it is expected that the neuroscience approach of human error will be connected with the engineering models. It is well-known that there are three kinds of response of human behaviour in the prototypical information process model as shown in Fig. 1, when one receives perceptive stimulation [3]. One is a skill-based

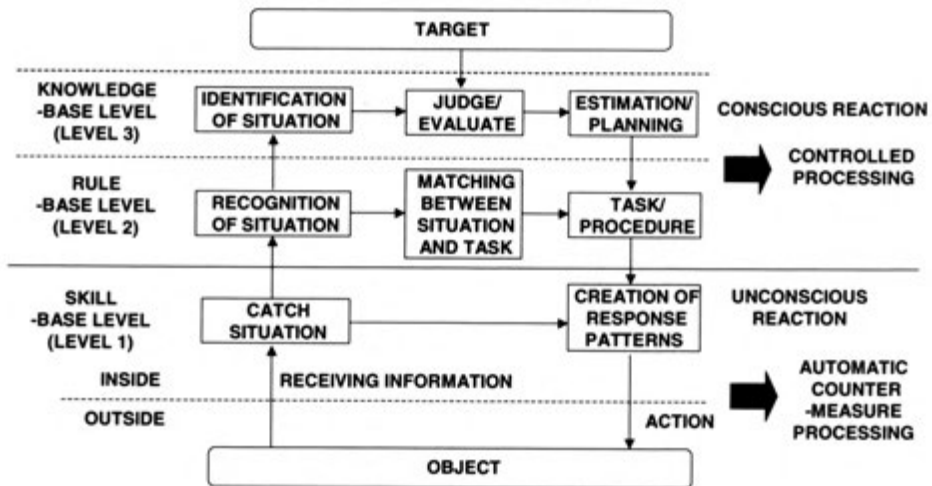


FIGURE 1. HRA Model.

response, which means the unconscious reaction. In this case, one can play a reactive action within the shortest response time after one receives some information on danger and creates the reactive patterns without the process of recognition, identification, judgment, and estimation. The second type of response is called a rule-based response, which consists of three kinds of information processes such as recognition of situation, matching between situation and task. The third type of response is called a knowledge-based response whose feature is an identification and judging process including in the total information processes. Since the latter two types of reaction are conscious reaction, the response time will be longer than unconscious reaction because of recognition process, identification process, judgment process or forecasting process.

In this paper an experimental paradigm is introduced for the measurement of visual field under the driving situation of load vehicle, in order to connect scientific model with the quantities of psychophysics and physiological signal obtained during the experiment. Another aims of this work is also to offer the efficient experimental system in order to measure a human function such as the visual field during ordinary work experimentally. It is also an additional aim to clarify the mechanism of human functions such as phenomena of visual tunnelling in scientific model.

2. Experimental paradigm

2.1. Experimental Equipments and Procedures

Figure 2 shows the schematic aspects of experimental devices. The response time and physiological signal are measured at the same time when the subject could recognize the target mark in CRT. The 21 inches CRT (SONY, GDM-F500) was equipped with 600 mm distance from the eye of the subject. A visual stimulus consists of foreground scene and background scene. As shown in Figs. 3, 4, the foreground scene is superimposed on the background scene by overlay unit as shown in the diagram of Fig. 2. The driving scene is edited as background scene for the combination of velocity and traffic demand as shown in Fig. 5.

The output data of NTSC signal from overlay unit is transformed into RGB signal by the up-scan converter in Fig. 2. All the scenes can be played back as 3D stereo image transformed NuVision's stereo display system (MacNaughton Inc, NuVision 21SX) consisted of liquid crystal modulator shutter, synchronizer, and stereo glasses. The shutter is a liquid crystal modulator that works in conjunction with stereo glasses to present the appropriate image to the left and right eye. The synchronizer accepts many video, input

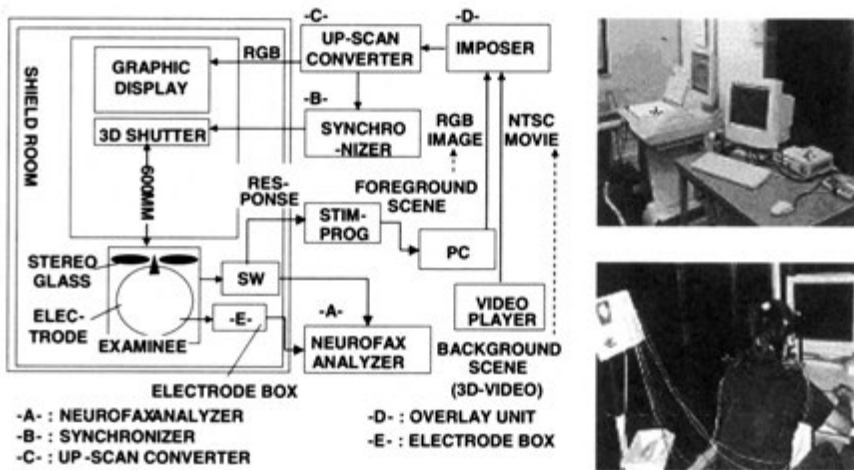


FIGURE 2. Schematic aspect of experiment.

configurations and automatically synchronizes the shutter with the display of stereo image on CRT. In order to watch 3D stereo image, the subject must wear stereo glasses. In the experiment it is tried to measure the region of the field of view by the response of a target mark in the foreground scene. On the other hand, in the background scene it is used to give a visual task with a situation of driving an automobile that works the noise for the recognition of target marks in the foreground scene.

Two kinds of buttons are given to the subject in the hands as shown in Fig. 3. The subject must push the button of right side as soon as possible, when one can detect or recognize the target mark S_2 in the foreground scene. On the other hand, the subject must put the mark of S_1 on by the left side

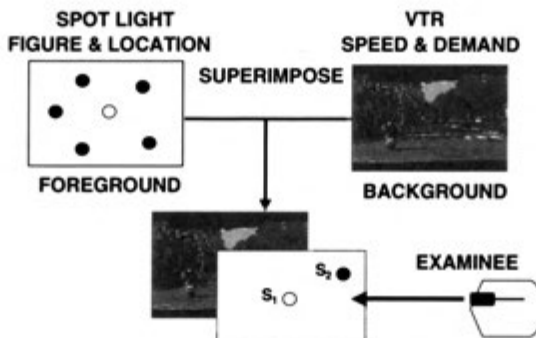


FIGURE 3. Foreground and background scenes.

button when S_1 disappears in order to fix the visual attention into the centre of the scene. Two kinds of visual task for the detection or recognition of S_2 and putting S_1 on are done during the experiment.

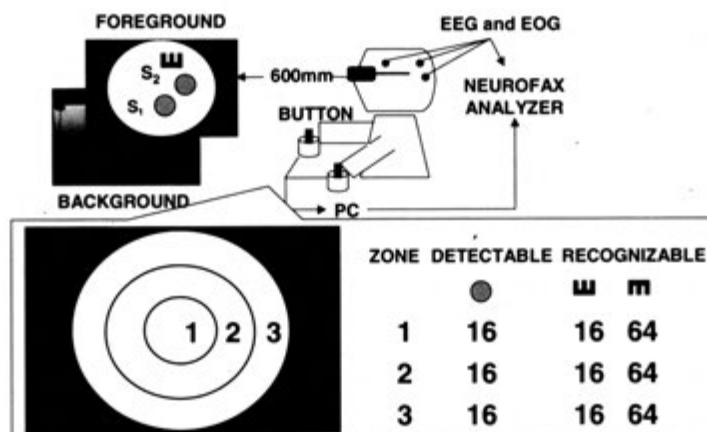


FIGURE 4. Appearance zone of target marks.



(a) V_1 and D_1



(b) V_1 and D_2



(c) V_2 and D_1








(d) V_2 and D_2

FIGURE 5. Background scene ($V_1 = 40$ km/h, $V_2 = 80$ km/h, $D_1 =$ non-crowded, $D_2 =$ crowded).

2.2. Foreground scene

The foreground scene plays a role to display a visual stimulus as a target mark. In the foreground scene, two kinds of marks of S_1 and S_2 are used as signals to measure the region of useful field of view as shown in Table 1. S_1 is used to keep the visual attention of the subject on the centre. S_1 is a simple white circle with the size of 0.48° . In this experiment the mark of S_1 appears during the specified duration time so that the subject must put on the mark of S_1 by the left side button when S_1 disappears. This is an additional task to recover the disappearance of mark S_1 . T is the factor of this additional task. The difference between T_1 and T_2 means the factor of frequency of disappearance of S_1 . S_2 appears within the zone (radius: $0^\circ \sim 14.03^\circ$) at undetermined coordinates whenever S_1 is appearing. There are two kinds of target marks of S_2 . The former is a simple white circle with 0.48° , and the latter mark is a specified shape in Snellen's chart whose shape is shown in Table 1.

TABLE 1. Random variables.

	DETECTABLE		RECOGNIZABLE	
	SHAPE OF SIGNAL	DIS APPEARANCE RATE	SHAPE OF SIGNAL	DIS APPEARANCE RATE
S_1	 0.48°	15cycles/min 53cycles/min	 0.48°	15cycles/min
S_2	 0.48°	---	 TARGET  STANDARD	---

2.3. Background scene

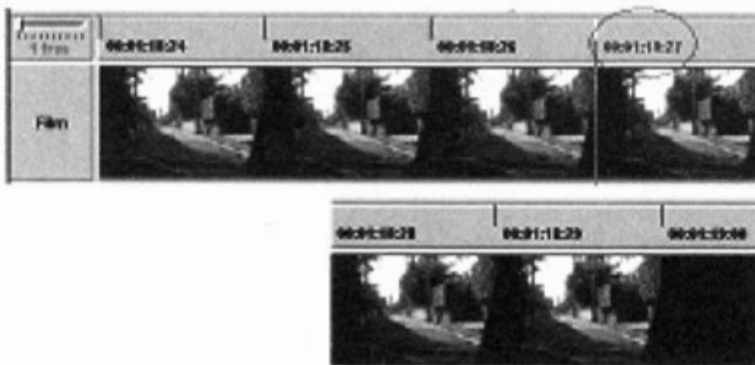
Several kinds of driving scenes are used as a background scene for the disturbance effect on the visual attention. Each image is recorded in actual road by 3D video camera KS55Z (Kastam, KS55Z). The patterns of driving scenes are shown in Fig. 5, where V and D mean the factors of the speed and traffic demand in the driving situation. The recorded scenes consist of two kinds of levels for factors V (velocity of automobile: $V_1 = 40$ km/h, $V_2 = 80$ km/h) and D (demand of traffic: $D_1 =$ non-crowded, $D_2 =$ crowded).

2.4. Measurement of human function by Experimental Design

For statistical test of experimental factors, the orthogonal table such as $L_8 (2^7)$ table was utilized to edit the background scene. As shown in Fig. 6, the background scene with specified combination of experimental factors such as V and D were edited in line with the combinations of orthogonal table, and the practical experiments were performed at random. Therefore, the relationship between psychological data and the experimental factors could be statistically tested by ANOVA.

No.	Velocity of automobile V	Traffic demand D	—	$V \cdot D$
1.	1	1	1	1
2.	1	1	2	2
3.	1	2	1	1
4.	1	2	2	1
5.	2	2	2	1
6.	2	2	1	2
7.	2	1	2	1
8.	2	1	1	1

(a) $L_8 (2^7)$ orthogonal table.



(b) Edit by DV-Editor.

FIGURE 6. Editing scenes by the sequence of $L_8 (2^7)$.

2.5. Measurement of human function by physiological signals

When the subject pushes on the switch with one's hand as a recognition signal of target mark, the trigger signal with the peak level (5 V) is sent to NeuroFax EEG-1518 (Nihon Kohden Inc.) or NeuroPack MEB-9100 (Nihon Kohden Inc.). At the same time, the duration time from the appearance of S_2 to the reaction by subject is saved in the hard disk of PC and several kinds of physiological signals are also measured by NeuroFax EEG-1518 or NeuroPack MEB-9100. In accordance with the kind of experiment, this signal is sometimes sent as a radio wave by acquired telemeter transmitter (WEB-5000, Nihonkoden Co. Ltd.) and received in telemeter receiver (WEB-5000, Nihonkoden Co. Ltd.) installed as a radio wave in the shield indoor. Received data are recorded in digital recorder (DR-M3, TEAC Co. Ltd.), which is placed in the front chamber. Transmitted data are confirmed as a wave in oscilloscope (V-212, Hitachi Co. Ltd.). During the measurement of response time as an action of pushing button, EEG is also an expression of human behaviour when the subject expresses the feeling in correspondence to the scene. Therefore, the physiological signals are also measured with the disc electrode attached based on ten-twenty electrode system illustrated in Fig. 7, when the response time to the scene presented by CRT was measured as a behaviour of subject by pushing the button.

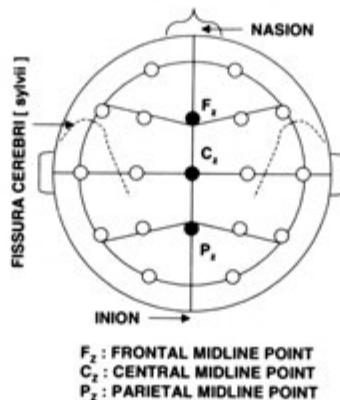


FIGURE 7. Ten-Twenty Electrode System.

3. Discussions

Table 2 shows the summary of the experimental results on effectiveness of factors that is evaluated from the experiment results for the measurement

of useful field of view whose detail of the experimental results is in [5]. The second row in Table 2 shows the results of the table of variance by ANOVA. In this analysis, it is seen by ANOVA that D and $D \times V$ were more effective factors.

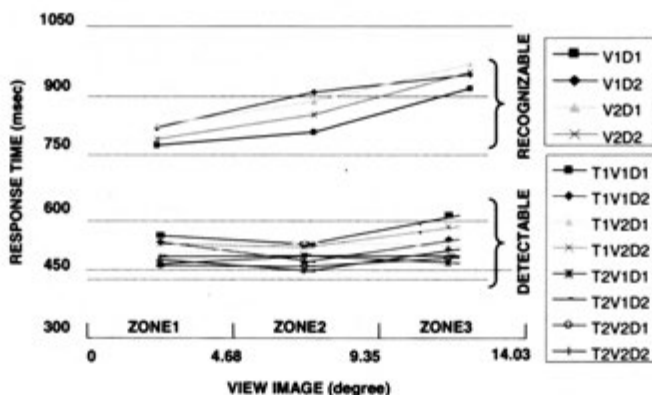
TABLE 2. Effectiveness of factors.

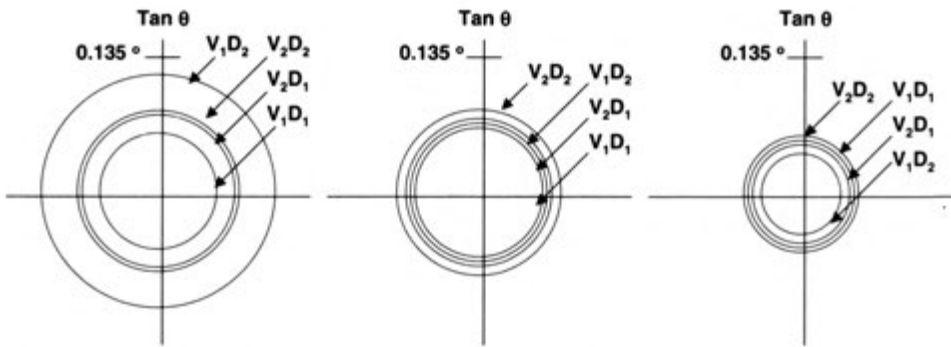
DETECTABLE	T	V	D	V multiple D	T multiple D	T multiple V
ANOVA	E*	N*	E	N	N	E
MEASUREMENT OF VISUAL FIELD	N	E	E*	---	---	---
RESPONSE TIME	E	N	N	---	---	---

RWCOGNIZABLE	---	V	D	V multiple D
ANOVA	---	N	E*	N
MEASUREMENT OF VISUAL FIELD	---	N	E*	---
RESPONSE TIME	---	E	E	---

E* : MORE EFFECTIVE
E : EFFECTIVE
N : LESS-EFFECTIVE
N* : NON-EFFECTIVE

The results of qualitative analysis on response time and width of the region of the useful field of view are shown in Figs. 8 and 9. From these results we conclude that the response time in experiment of a detectable is smaller than that of a recognizable for every combination of V and D . On the other hand, it is also found that the region of visual field in a recognizable is

FIGURE 8. Response time of S_2 .



(a) Detectable field at T_1 . (b) Detectable field at T_2 . (c) Recognizable field at T_1 .

FIGURE 9. Useful field of view by detectable and recognizable experiment.

narrower than that in a detectable. As shown in Fig. 9, the regions of useful field have been obtained for the various kinds of experimental conditions.

In order to verify the validity, the event related potentials (ERP) are measured in the experiments, since it is seen that ERP are the potentials related to the specified cognition process. Especially, for the verification of the existence of the channels in the visual information processing, P300 is studied. Figure 10 shows an example of obtained potentials P300 on Cz. Since the degree of this related potential of P300 designates how much concentration has been done under the psychological uncertainties, it is estimated that this

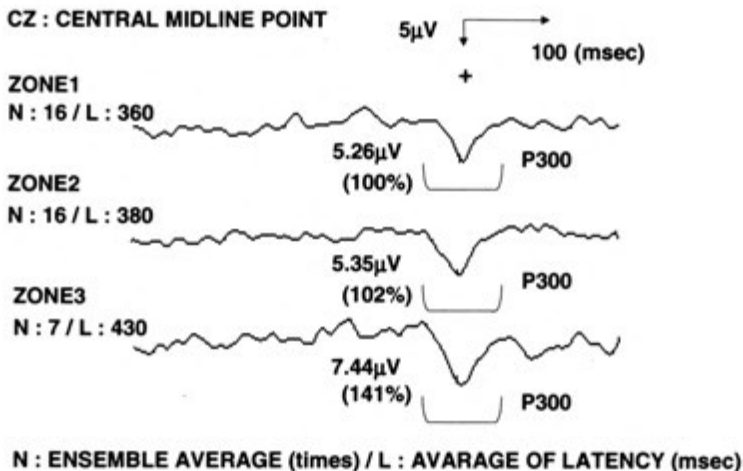


FIGURE 10. Event related potentials P300 on Cz.

signal is in proportion to the depth of information processing when one must judge whether the mark appears or not during recognizable experiment.

Therefore, it was suggested that the degree of visual attention such as depth of processing in the cognitive model proposed by Miura [6] could be verified by this experiments. From this point of view, the difficulties of the visual tasks could be estimated as an ensemble average of this related potentials for each zone in Fig. 10. It can be seen that the results of Fig. 10 shows the concentration of visual attention, since the voltages of related potential for each zone which means the depth of processing coincides with the results of response time in Table 2.

4. Conclusion

A new experimental paradigm has been successfully proposed for the evaluation of visual field at the situation of driving a load vehicle. In the paper some primitive experiments such as the region of useful field of view have been studied from the viewpoint of psychological method and neuroscience approach. Especially, for the verification of the proposed channels of visual information processing could be performed by the experiment of neuroscience such as the measurement of ensemble average voltages of event related potential which reflects the degree of activity of high order function of brain.

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