A New Method for Evaluating Mental Work Load in n-back Tasks

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ABSTRACT

It is important to evaluate mental work load since the evaluation will be useful for managing operator's work load or for preventing from overloaded tasks. However, there does not exist any quantitative method for evaluating mental work load. This motivates the study of proposing a new method to evaluate the influence of mental work load caused by information processing demand. Our method focuses on involuntary eye movement of human, which is vestibulo-ocular reflex (VOR). The eye movement occurs reflexively for gaze stabilization while paying attention to the target. We have investigated the influence of mental work load on VOR using a new model-based method. The first step of the method is to identify the eye movement model for a particular subject from measured data without any secondary task. This model represents the subject's dynamics of VOR. After that the eye movement is measured when the subject get distracted by paying attention to secondary tasks, and it is compared with the identified model output. This method makes it possible to assay the influence of mental work load on VOR. This study has investigated the influence of mental work load on human eye movement by giving n-back tasks as the secondary task. By varying the amount of information processing demand of n-back tasks, we compare the variations of the dynamics of VOR from the identified model which represents human VOR dynamics in ideal situation. Consequently, we give a proof of quantitatively evaluating mental work load using our proposed model based method

1. INTRODUCTION

We have proposed a new method to evaluate quantitatively mental work load on car drivers based on a model-based approach [1], [2]. In the method, the mathematical model represents the dynamics of vestibule-ocular reflex when the driver pays his attention to driving the car safely. The driver's dynamics of vestibule-ocular reflex (VOR) change according to his degree of concentration on driving. That is to say, the dynamics change evidently when the distractions affect on his driving attention. Similarly to VOR, saccarde and smooth-pursuit in eye movement have been studied in relation to the problems of voluntary movements and selective attentions [3], [4]. Reflective eye movements including VOR have been studied in relation to information processing demands. Furman [5] investigated the effect of visual inputs on VOR by measuring times spent for responding to given cues. The research suggests that the effect of the given task may be appeared as the increase of reaction time.

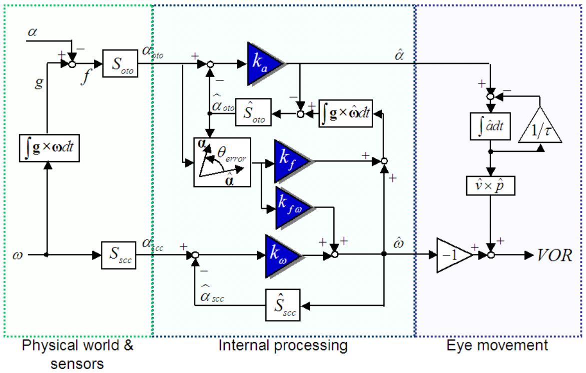
On the other hand, working memory as a function of human brain attracts researchers' attentions because invasive imaging of brain functions has become possible. Moreover, tasks in association with working memory are very sensitive to information processing demands [6]. Thus, it is relatively easy to evaluate the effect of information processing demands on working memory. However, we can not obtain clear understanding from these studies, and do not have methods for quantitative evaluation or more precise analysis on information processing functions under conditions of multiple tasks..

In this paper, we proposed the method for quantitative evaluation of mental work load in n-back tasks, and show the effectiveness with experimental results.

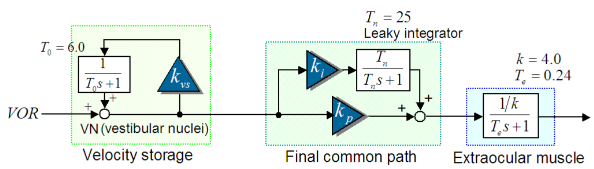
2. MODEL OF EYE MOVEMENT

A. Model of VOR

A block diagram of the proposed eye movement model is shown in Fig.1. We assume in this study that a subject performed a verbal n-back task with vibration of the seat and is asked to keep his gaze at a fixed point. Then, VOR is continuously evoked to stabilize his point of gaze against disturbance on the head position during the task. The VOR model which has been proposed by D. M. Merfeld. et al [7] is a mathematical model that represents the dynamics of human VOR response in three dimensions and is shown in Fig.1 (I). This VOR model expresses the interaction of human semicircular canals and otolith, which sense the head rotation and orientation.



(I) VOR part proposed by Merfeld 2002



(II) Velocity storage & final common path part proposed by Robinson 1981

Fig.1 Model of vesibulo-ocular reflex.

Moreover, it contains human internal processing to estimate a predicted value that is the feed-forward signal to generate motions of eyeball against disturbance on the head position [7]. The angular velocity and linear acceleration of the head in three dimensions are the inputs to this model. Then, it outputs the angular velocity of eyeball in three dimensions. It has been suggested by Robinson [8] that the eventual angle of eyeball, which defines the gaze direction, is not a simple integration of the angular velocity. The transformation from VOR output to the angle is shown in Fig.1 (II). The signal is modified through velocity storage, final common path and extraocular muscle. Consequently, we apply this composed VOR model as the eye movement model of a subject.

B. Model Identification

So as to evaluate mental work load during n-back task, we use the eye movement model of each subject. The model must be identified in advance from the experimental data of eye movement which is estimated from rotation of an optokinetic pattern (black-white stripe). The VOR model contains nine gain parameters. These parameters have been determined by minimizing the error between the measured output and the model output. The VOR movements were induced by shaking the subject with moving chair while he is asked to stabilize his eye on the center of screen. The experimental setup and sensors setting is given in Fig.3.

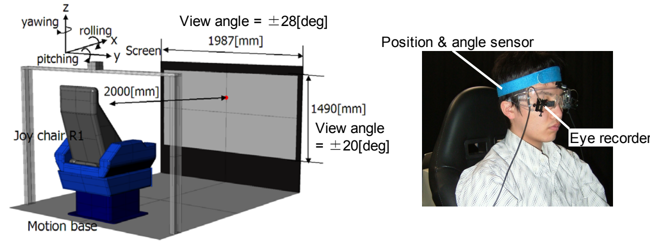


Fig.2 Experimental setup and sensors setting.

We have applied genetic algorithm with local search of gradient method to estimate the parameters which minimize the error norm expressed by

$$J = \sum_{i=1}^{N} \{\theta_{obs}(i) - \theta_{mdl}(i)\}^2 . \quad (1)$$

where θ_{obs} is time series with three dimension sampled from the observed data of eye movement, θ_{mdl} is time series estimated by the model. Before the identification, the measured eye movement has been treated with outlier removal process that extracts the rapid eye velocity data, which includes blinking and saccade. This is because the dynamics of VOR does not have any relation to blinking and saccade.

The identified model makes it possible to obtain the estimate of the eye movement. It represents the VOR dynamics of a particular subject who is asked to put his gaze on the center of front screen and is not distracted by any other task. We can use the model to evaluate online the deviation on eye movement when some distraction is given as secondary task.

C. Identification Results

An example of the identification results is shown in Fig.3. The time responses ((a) (I) and (II)), and the frequency responses of measured eye movements ((b) (I)) and the estimates from the model ((b) (II)) are compared in the figure. We apply the values for gain parameters as the initial values of search procedure which have been suggested in Merfeld [7] and Robinson [8]. The frequency responses are shown in power spectra and the coherence between the measured eye movements and the predicted values from the identified models. The coherence is defined as

$$\gamma^2_{xy}(f) = \frac{|C_{XY}(f)|^2}{P_{XX}(f)P_{YY}(f)} \quad (2)$$

where $P_{XX}(f)$, $P_{YY}(f)$ are power spectra of the measured eye movement and the predicted signal, respectively, and where $C_{XY}(f)$ is cross spectrum between them. The coherence takes unit value when the relation of two signals can be described by a linear differential equation.

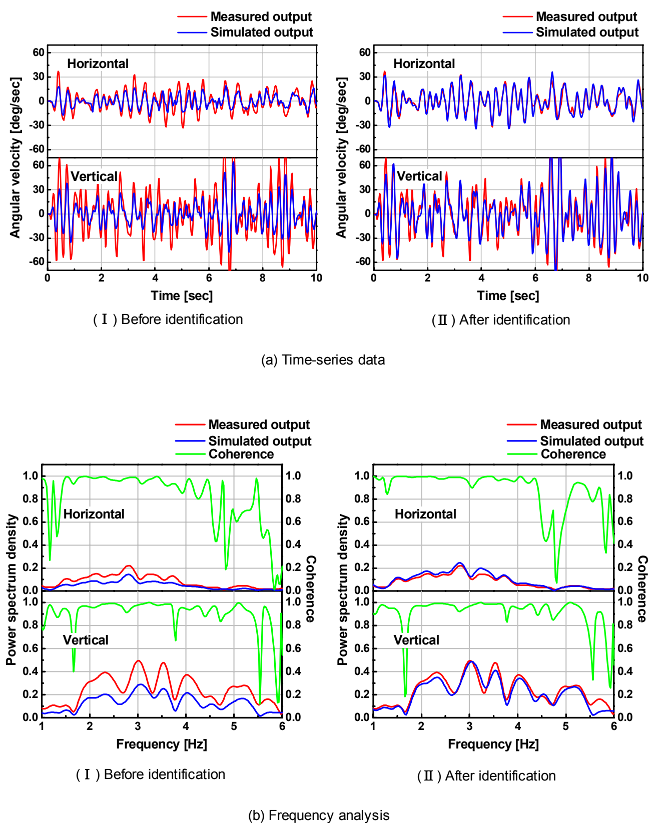


Fig.3 Example of identification result.

We can confirm from Fig.3 that the identification has resulted in a good matching of the model to represent the subject's dynamics of eye movement both in the time responses and frequency responses. We conducted experiments with three subjects for obtaining the identified models. The results show that the averages of predicted errors in three subjects were from 3 degree to 6 degree during eye movements for the range of 20 degree in horizontal and 30 degree in verticality. It should be noted that the identified parameters vary in a certain range in three subjects. This suggests a further research to understand the variation in individuals.

3. METHOD OF EXPERIMENT

A. Experiment Procedure

The proposed eye movement model is described in II with the block diagram Fig.1. We assume in this study that a subject performed a verbal "n-back" task with seat vibration and is asked to keep his gaze at a fixed point of screen. Then, VOR is continuously evoked to stabilize his point of gaze against disturbance on the head position during the task. In the "n-back" task, subjects must decide for each verbally presented letter whether it matches the letter presented n items back in sequence. The subject was required to respond every 2.5 seconds with push switches as shown in Fig.4. The time length of one trial was 30 seconds. Thus, the subject was required to respond for 12 questions per one trial. Three subjects (ages 20-24, males) participated in the work.

The "n-back tasks" require to the subjects for holding /updating information, and decisions based on it. Working memory acts dynamically for such functioning during "n-back tasks". Several researches of imaging brain functions by MRI have provided the observations that frontal association area, temporal association area, and Broca's area activate during "n-back tasks" [9], [10].

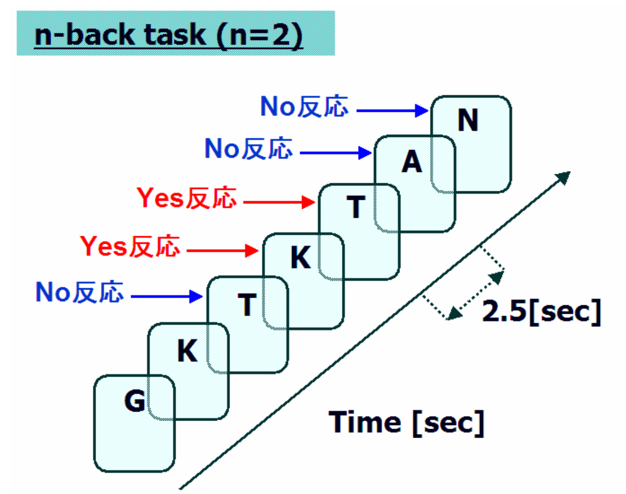


Fig.4 Verbal n-back task.

The experimental procedure is as follows:

1) The subject was asked to sit in moving chair and to keep his gaze at red point of screen.

2) Four types of task were given to respond with push switches. Those are simple reaction task, "1-back, 2-back, and 3-back tasks". In each trail, the subject was required to respond every 2.5 sec using switches whether the answer was yes or no.

3) Three trials were conducted for each type of task. The eye movements and reaction times to every verbal presentations of letter were recorded.

B. Results of Experiment

The experimental results are shown with the proportion correct (the rate of right answers) and the reaction time :

the average and the standard deviation in Fig.5. The reaction times are normalized by the average time of simple reaction task. The proportion correct goes down a little as "n" increases; on the other hand, the reaction time goes up apparently. These results suggest that the subject takes a certain time for manipulating remembered information in working memory and the time spent increases as the movements and the predicted signals

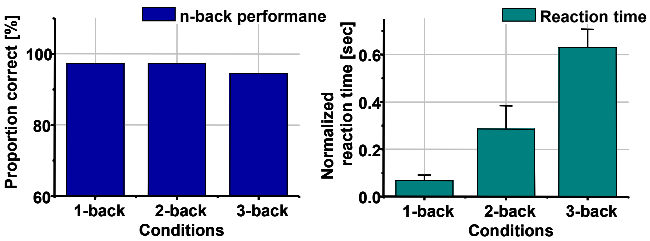


Fig.5 Experimental results.

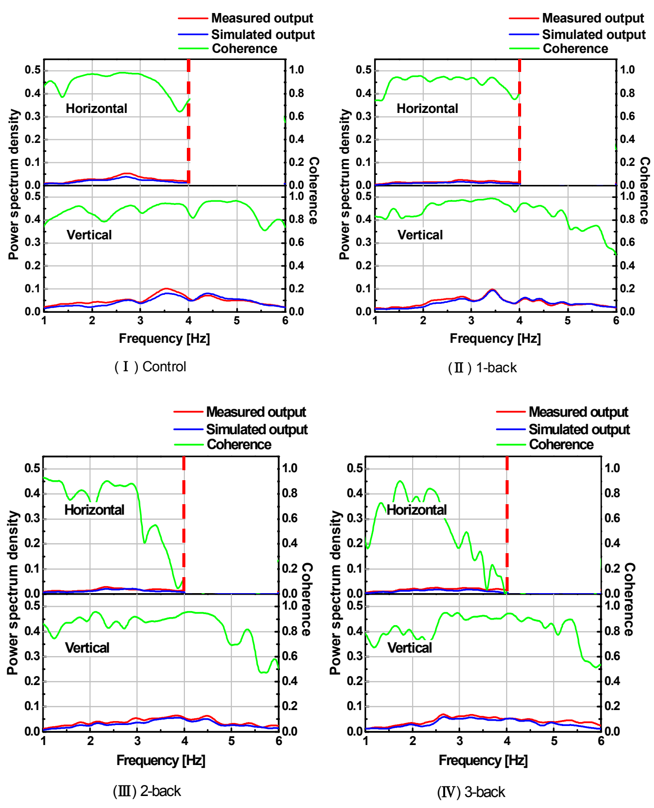


Fig.6 Comparison of coherence and power spectrum in the tasks.

from the identified VOR information increases. The power spectrum and coherence between the measured eye movements and the estimates from the identified model are shown in Fig.6. It is noted that the frequency range higher than 4 Hz in the horizontal direction contains less power because of spectrum of seat vibration. We can not find out any clear difference in power spectra in all cases. The curve (II) of coherence for "1-back task" is similar to the control (I). The coherence of "2-back" (III) and "3-back" (IV) take lower values in almost frequency range in comparison with the control (I). This means that the dynamics of VOR change in "2-back and 3-back tasks". The averages of coherence over 1 Hz to 4 Hz in "n-back tasks" for all subjects are shown in Fig.7 in comparison with the control condition and simple reaction task. The results of t-test are also shown in the figure. The results suggest that online evaluation of mental work load is possible by calculating frequency characteristics of eye movements with the reference model under control condition. In addition, we calculated phase shift between the measured eye movement and the predicted signal of the VOR model. Certain phase shifts were observed when "n-back task" was given. In order to complete the analysis on the phase shift, we may have to take the time-varying properties of the signals into consideration.

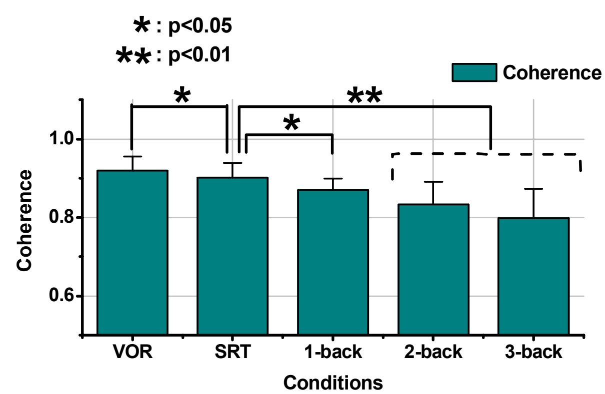


Fig.7 Evaluating influence of working memory on coherence average (all subjects).

4. CONCLUSION

This study identified the eye movement model, which represents the dynamics of VOR. It is shown with experimental results of verbal "n-back tasks" that the information processing demand caused by the tasks affects involuntary eye movement for gaze stabilization. In addition, a model-based method has been proposed to quantitatively evaluate the influence of demanded tasks on VOR dynamics. It is shown that the results of evaluation have a relationship to the demanded memory amount. Consequently, our proposed model-based method makes it possible to quantitatively evaluate the effect of demanded tasks. It is worth to mention that the proposed model-based evaluation method can be carried out in real time. It has the possibility to estimate the information processing demand to human operators on the tasks and jobs. It also has the potential to be applied to a driver assistance system or information control system for in-vehicle HMI.

Further research will be devoted to investigating other factors, for examples, time-varying characteristics of VOR and the difference of the dynamics among individuals. In addition, further research will aim to establish a method to estimate not only the depth of influence of demanded tasks but also the timing when a subject gets distracted from his primary task. The estimation of timing makes it possible to give the operator warning. This kind of warning may be useful for driver assistance system of vehicles.

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