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Relation between Human Alertness, Velocity Wave Profile of Saccade, and Performance of Visual Activities

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Abstract— **Practical method for assessing human alertness is desired for preventing traffic accidents caused by drowsiness in the drivers. In this article, we examined relation between saccade profile (PV/D), which was reported to have dependency on the alertness, and visual activities to investigate an applicability of the saccade for assessing the alertness in vision-dependent circumstances such as driving. We defined a new parameter of visual activity as "bit rate of visual perception (BRVP)", and analyzed relations of saccade velocity profile to the BRVP, relative pupil diameter, and critical fusion frequency. The results showed significant high positive correlations between PV/D, BRVP, and relative pupil diameter.**

Keywords—**Bit rate of visual perception, critical fusion frequency, pupil diameter**

I. Introduction

Practical method for assessing human alertness is desired for preventing traffic accidents caused by drowsiness in the drivers. Although bioelectric signals such as EEG [1] or skin potential [2] are commonly used for the assessment of the alertness fluctuation, most of conventional methods have a disadvantage in requiring attachment of electrodes or devices on the body surface for detecting the signal. Whereas we have shown in the previous researches that sharpness of the velocity wave profile of saccade has a dependency on human alertness [3], [4]. This phenomenon may have applicability to the practical alertness assessment, because photometric measuring device of saccadic eye movements is likely to be developed using image sensors located in front of the face in the future [5]. However feasibility investigation to apply saccade dynamics for preventing the traffic accidents is insufficient from the viewpoint that variations in spectrum power of EEG were mainly referred to indices of alertness fluctuations in our previous studies. Since the accidents are not directly caused by decline in brain activities but by depression in visual functions due to decreased brain activities, it is necessary to analyze the relation between alertness, saccade dynamics, and performance of visual activities.

In this paper, we examined relation between velocity wave profile of saccades, which was reported to have a dependency on alertness, and performance of visual activities. We defined a new parameter "bit rate of visual perception (BRVP)" as an index of the performance. Also we measured pupil diameter and critical fusion frequency (CFF) as the references of the visual activities.

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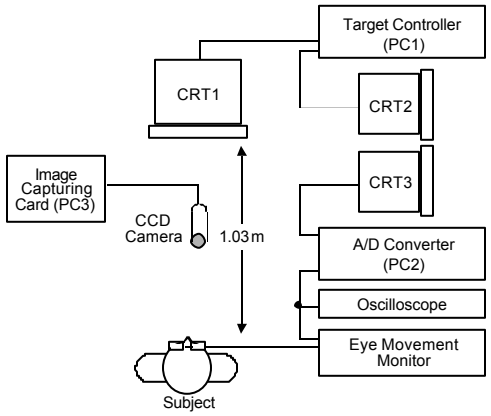


Fig. 1. A scheme of experimental setup.

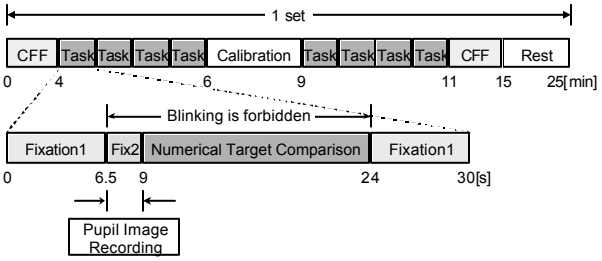
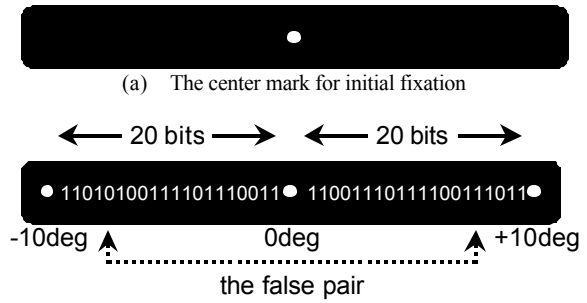


Fig. 2. Time chart of the experimental protocol.

II. Methods

A. Subject and Apparatus for Measuring

One male, aged 22, participated in the experiments. Informed consent was obtained from the subject. The subject was seated at the distance of 1.03m from the CRT1 as shown in Fig. 1. Horizontal eye movements are detected by the infrared limbus reflection system. Eye movement data were sampled at 1kHz. Ocular images were recorded with a CCD camera and captured at 15fps. CFF was tested with the dedicated device.



(a) The center mark for initial fixation

(b) A pair of 20-bit binary codes for the comparison task

Fig. 3. A scheme of experimental setup.

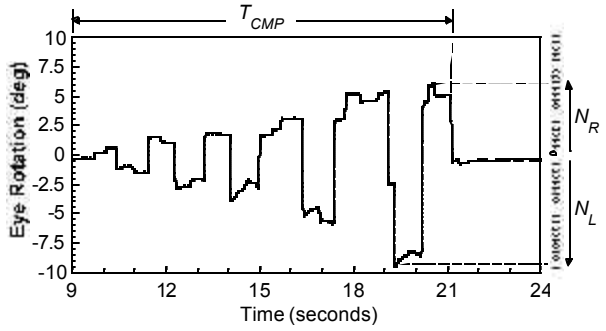


Fig. 4. A sample record of eye movement and the parameters for calculating the BRVP.

B. Procedures of the Experiment

Fig. 2 shows time chart of the experimental protocol. The experiment consisted of "CFF measurement", "Task", "Calibration" and "Rest". In the "CFF measurement" session, CFF was tested twice at ascending frequency condition, and also at descending frequency condition respectively. In the "Task" session, the subject performed a numerical comparison task, and monocular eye rotations were recorded during the task. In the task, a pair of 20-bit binary codes is presented horizontally and symmetrically from the center mark on the CRT 1 (Fig. 1 and Fig. 3). The binary codes are symmetrically almost the same except one bit. The subject was instructed to compare corresponding binary digits alternately on the right and the left side in order from the center to the exterior, and to fixate the center mark after recognizing the false pair of the digits. Presentation of the codes continued 15s after recording pupil images for 2.5s. The "Task" session was repeated 8 times for one set. Totally 10 sets were conducted in the experiment. All experiments were carried out in a darkened room

C. Eye Movement Analysis

The ratio of peak velocity and duration (PV/D) of the saccade was calculated for each velocity waveform as an index of sharpness of the velocity wave profile. PV/D was reported to have a dependency on alertness in our previous researches. Mean PV/D was computed for every set of the experiment.

TABLE I
CORRELATION COEFFICIENTS BETWEEN THE PARAMETERS OF PV/D, BRVP, RELATIVE PUPIL DIAMETER, AND CFF

	PV/D	BRVP	Relative pupil diameter	CFF
PV/D	—	0.73*	0.92**	0.46
BRVP	—	—	0.72*	0.73*
Relative pupil diameter	—	—	—	0.49
CFF	—	—	—	—

* $p < 0.05$, ** $p < 0.01$

D. Analysis of Visual Activities

BRVP was computed by equation (1).

$$BRVP = \frac{N_R + N_L}{T_{CMP} - \sum_{i=1}^{n} D_i} \quad (1)$$

where N_R and N_L are numbers of the figures compared in the right and the left codes in the task as shown in Fig. 4. T_{CMP} is the time required to fixate the center mark in the task. Thus the BRVP means the time rate at which information is perceived within the brain through the retina during the task. The BRVP has the unit of bps.

Maximum pupil diameter in each "Task" session was manually measured using an image processing software. The maximum diameters were divided by the diameter in the first session for normalization. Mean relative pupil diameter was calculated for each experimental set. Also mean CFF was computed for the each set.

III. RESULTS AND DISCUSSION

A. Correlation between PV/D and Visual Functions

As can be seen in Table I and Fig. 5, significant high correlations of the PV/D to the BRVP ($r=+0.73$, $p<0.05$) and to the relative pupil diameter ($r=+0.92$, $p<0.01$) were obtained. Since decrease in the PV/D reflects decline in alertness of the subject according to our previous results, Fig. 5(a) indicate that the BRVP has a tendency to decrease with decline in the alertness. This result implies that when the subject is conducting slow saccade (i.e. small PV/D), the perceptual performance of the subject is in low activity, and vice versa. Since the previous study showed decline in PV/D reflects decline in alertness, this results infer that when the subject are in low alertness state, perceived information in a unit of time through retina is small.

On the other hand, pupil diameter is reported recently to have a relevancy not only to alertness [6], but also to

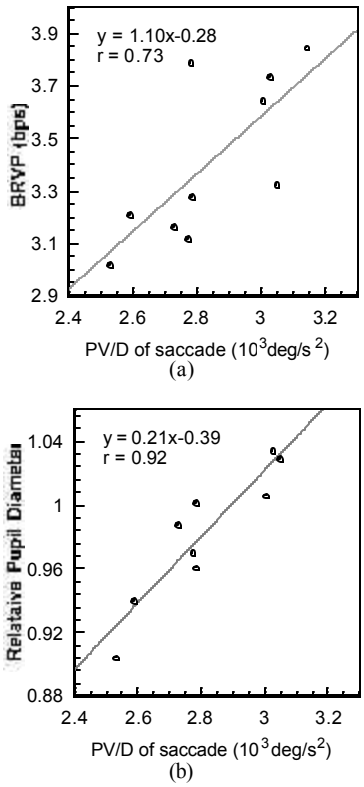


Fig. 5. Correlations between PV/D of saccade and visual activities of BRVP and relative pupil diameter.

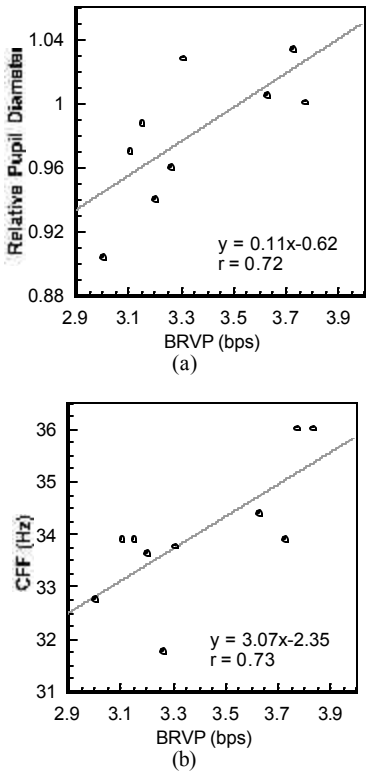


Fig. 6. Correlations of BRVP to relative pupil diameter and to CFF.

information capacity of retinal image [7]. According to this article, decrease in the pupil diameter in sufficiently darkened condition results in degrading the quality (i.e. reducing the information capacity) of the retinal image. Consequently, Fig. 5(b) infers that external image information may be reduced at the retinal stage with the reduced alertness level.

B. Correlation between BRVP and Other Visual Activities

Fig. 6 shows correlations of the BRVP to the relative pupil diameter and to the CFF. These results also had significant high correlations as in Table I. Fig. 6(a) indicates more directly the relation between the throughput of the visual system and information capacity acquired through retina as remarked above.

Since CFF value can be regarded as an index reflecting time resolution of vision including higher central nerve's system, Fig. 6(b) implies that decline in BRVP may be caused not only by decreased information capacity at retina but also by decreased time resolution in the vis ion system.

IV. CONCLUSION

We examined the relation between velocity profile of saccades and performance of visual activities of BRVP, relative pupil diameter, and CFF. The results showed significant high positive correlations between PV/D, BRVP, and relative pupil diameter. This indicates an applicability of saccade dynamics for assessing alertness in vision-dependent circumstances such as driving.

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