Proceedings - 19th International Conference - IEEE/EMBS Oct. 30 - Nov. 2, 1997 Chicago, IL. USA

BLUNTNESS OF SACCADIC EYE MOVEMENT DEPENDING ON VIGILANCE STATES - EXAMINATION BY MODEL SIMULATION -

Akinori Ueno†* Tsuyoshi Tateyama† Moriichiro Takase†† Haruyuki Minamitani†

†Institute of Biomedical Engineering, Faculty of Science and Technology, Keio University, Hiyoshi 3-14-1, Kohoku-ku, Yokohama, Kanagawa 223, Japan
††School of Medicine, Keio University, Shinanomachi 35, Shinjuku-ku, Tokyo 160, Japan
*E-mail address : ueno@bmel.elec.keio.ac.jp

Abstract— In our previous research we revealed that eye velocity become blunt during saccade as vigilance state get lower. In this study we examined bluntness of saccade velocity by simulating saccadic eye movements using a model of saccade generation. Blunt saccade was achieved by way of changing parameters of pulse generator in the model. Adequate values of the model parameters to 4 typical experimental data were assumed by fitting simulated eye velocity to the experimental eye velocity. Comparison of the values of the model parameter to α power calculated from the EEG measured with saccade revealed a high correlation between characteristics of pulse generator and vigilance states. Since pulse generator exists in pontine reticular formation, which also belongs to controlling system of vigilance state, it was suggested from the results that decline in the activity of pulse generator in brain stem caused to the blunt saccade.

I. Introduction

It was reported in previous study that blunt saccade (saccadic eye movement) was observed when vigilance state is low and that bluntness of saccade velocity related to the degree of vigilance state[1][2]. But the cause of bluntness and its relation to the vigilance states is not still clear. In this paper we examined possible factors influencing eye velocity during saccade by modelling and simulating saccadic generation based on the concept that burst neurons in the brain stem are driven by motor error.

II. Methods

A. Description of the Model of Saccade Generation

For simulating blunt saccade we constructed a model of saccade generation. In study of horizontal saccade, a model proposed by Robinson in 1964[3] is commonly considered as a confidential basical model. But it doesn't have detailed expressions concerning to the pulse generator, which codes velocity signal of saccade to the motoneurons. In 1981 Van Gisbergen et al proposed a model of saccade generation based on the concept that burst neurons are driven by motor error[4]. Since Gisbergen's model has sufficient expressions about pulse generator, we combined Robinson's model and Gisbergen's model to used for the simulation.

A scheme of the model used for simulation is illustrated in Fig. 1. Basically the model can be categorized into 4 parts corresponding to (a) to (d) in Fig. 1. The function of part (a) is to translate the input based on retinal coodinate to the data based on head coodinate and to generate trigger of saccade. The part (b) is so-called pulse generator which codes saccadic velocity signal. Burst rate of the pulse generator relates to the eye velocity and is approximately determined according to the equations (1) and (2).

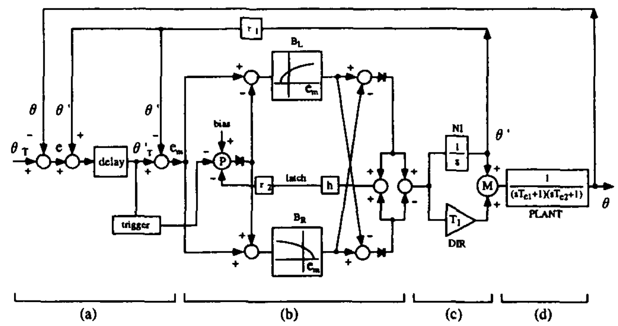

Fig. 1. A scheme of model of saccade generation based on the concept that burst neurons are driven by motor error. θ is orientation of the eye in the retina, θ' is orientation of the eye in the head, θ_T is orientation of the target in the retina, and θ'_T is orientation of the target in the head.

$$B_L(e_m) = \begin{cases} b_m(1 - e^{-(e_m+e_0)/b_k}), & e_m \geq -e_0 \\ 0, & e_m < -e_0 \end{cases} \quad (1)$$

$$B_R(e_m) = \begin{cases} b_m(1 - e^{(e_m-e_0)/b_k}), & e_m \leq e_0 \\ 0, & e_m > e_0 \end{cases} \quad (2)$$

where B_L and B_R are burst cell firing rates in left and right burst cell, e_m (motor error) is the difference between instantaneous eye position and desired eye position in the orbit, and b_m, b_k and e_0 are invariable that characterize the pulse generator. The part (c) consists of integrator and direct part. The function of the integrator is to make signal associated with the torque against restoring torque, which is made by viscosity of tissues surrounding the eye. Finally both direct and integrated signals are combined

(0-7803-4262-3/97/$10.00 (C) 1997 IEEE)

TABLE I
STANDARD VALUES OF MODEL PARAMETERS USED FOR SIMULATION.

Pulse Generator			Eye Plant	
$b_m[deg/s]$	$b_k[deg]$	$e_0[deg]$	$T_{e1}[s]$	$T_{e2}[s]$
1100	10.0	2.0	0.015	0.004

and coded to eye plant. In the part (d) of eye plant, including lateral and medial recti, pulse data are changed into movement of eyeball (i.e. saccade). Standard values of model parameters we used are shown in the TABLE I.

B. Acquisition of Experimental Data

For application of the model to experimental data, we executed target tracking task to one subject and obtained experimental data. In tracking task a preceding target appears for 2s at 0deg from the center of the display, then it jumps to one of a probable position of 2.5, 5.0 or 7.5deg and disappear 1s later. In the task this sequence was repeated for 3min and was executed at 11, 13, 15 o'clock. Eye movement and EEG from the scalp of Fz, Cz and Pz were measured.

C. Simulation of the Model

In the model in Fig. 1 there are 4 probable parameters to effect bluntness of eye velocity during saccade, those are b_m, b_k, T_{e1} and T_{e2}. Preliminary trial of changing these 4 parameters revealed that b_m and T_{e2} are dominant to the output of the model. To achieve similar output to selected 4 typical experimental data in different vigilance state, we varied these 2 parameters and evaluated the similarity to the experimental data by calculating the summation of absolute error between simulated data and experimental data. Values of model parameters of b_k, e_0 and T_{e1} were fixed to the standard values in TABLE I.

III. Results

Fig. 2 illustrates examples of experimental data and simulated data. The upper figure is time course of eye position containing generation of saccade and the lower figure is time course of eye velocity calculated by derivation of the eye position data above. As can be seen in Fig. 2 simulated data (solid line) agreed with the experimental data (dotted line). Fig. 3 shows relation of velocity error to b_m and T_{e2}. The values of b_m and T_{e2} written in Fig. 2 was determined by this result at point of the smallest velocity error.

We applied the same analysis to the other 3 experimental data and investigated the relation of velocity error to b_m and T_{e2}. From the results of velocity error it was found that T_{e2} values stable and that it only varies from 0.015 to 0.020. Then we fixed the value of T_{e2} at 0.018 and determined b_m from the relation of velocity error to b_m.

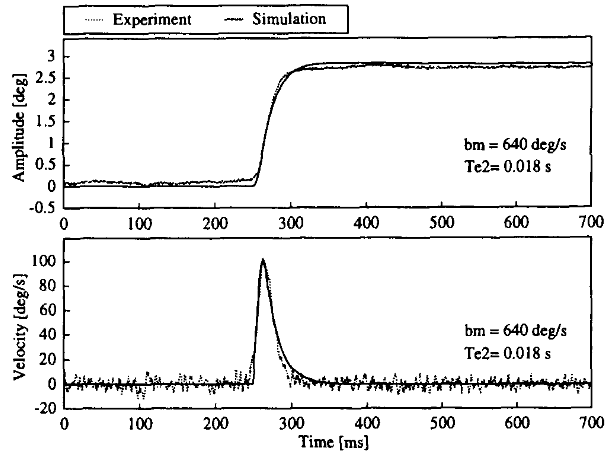

Fig. 2. Examples of eye position and eye velocity during saccade.Dotted line is experimental data. Solid line shows simulated data when b_m is 64deg/s and T_{e2} is 0.018s.

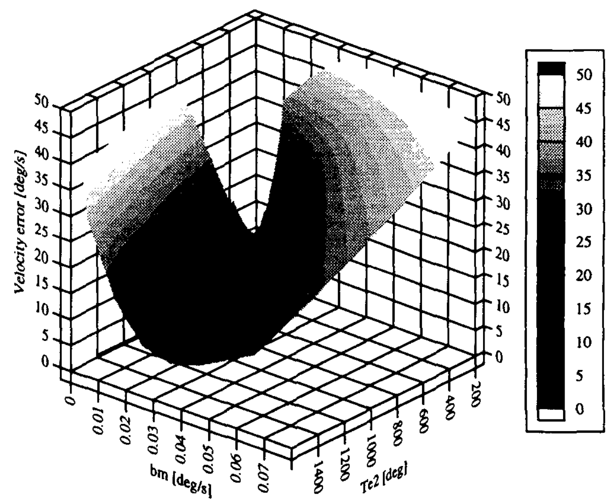

Fig. 3. An example of relation among b_m, T_{e2} and velocity error between experimental data and simulated data. Density of the black color correspind to the amount of velocity error. The more dense, the smaller velocity error become.

Fig. 4 shows relation between b_m and spectral power of α wave band (α power) extracted from the EEG data which was measured with eye movement during target tracking task. As can be seen in Fig. 4 a negative high correlation between b_m and α power was observed. Since the increase of α power means decline in the vigilance states, this correlation means that according to the decrease of vigilance states b_m, which can effect on the firing rates of pulse generator also decays.

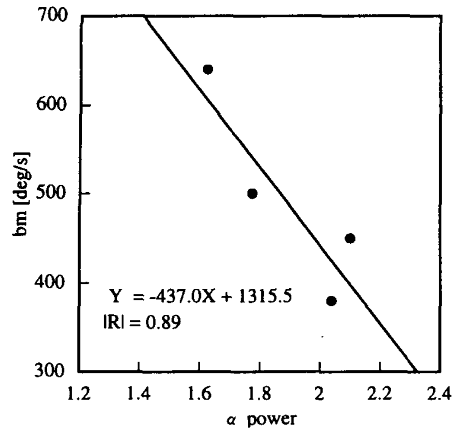

Fig. 4. Relation between model parameter of b_m and experimental parameter of α power which reflects vigilance states.

IV. Discussion

Since b_m is associated with firing rate of pulse generator, high correlation between α power and b_m in Fig. 4 implies that there are some factors (or a factor) which have some relation with vigilance states and characterise the activity of pulse generator. In physiological study it is known that pulse generator exist in pontine reticular formation, and also known that temporal vigilance states is controlled by reticular controlling system. As the pontine reticular formation is contained to reticular controlling system, there is a possibility that activities of pulse generator in the pontine reticular formation are inhibited while vigilance state is low and that it reduced firing rates of burst cell, so that eye velocity become blunt during saccade.

V. Conclusion

By simulating blunt eye movement during saccade using the model based on the concept that burst neurons are driven by motor error, it was suggested that decline in the vigilance states cause to the decline in the activity of pulse generator in brain stem and that this cause to the reduce of firing rate in pulse generator, so that eye velocity become blunt during saccade.

References

[1] A. Ueno, Y.Ota, M. Takase, H. Minamitani, "Relationship between vigilance states and characteristics of saccadic eye movement," in *Proc. 17th Ann. Int. Conf. IEEE Eng. Med. Bio. Soc.*, pp.572-573, 1995.

[2] A. Ueno, Y.Ota, M. Takase, H. Minamitani, "Parametric analysis of saccadic eye movement depending on vigilance states," in *Proc. 18th Ann. Int. Conf. IEEE Eng. Med. Bio. Soc.*, pp.319-320, 1996.

[3] D. A. Robinson, "The mechanics of human saccadic eye movement," *J. Physiol.*, vol.174, pp.245–264, April, 1964.

[4] J. A. M. Van Gisbergen, D. A. Robinson and S. Gielen, "A quantitative analysis of generation of saccadic eye movements by burst neurons," *J. Neurophysiol.*, vol. 45, no. 3, pp.417–442, March, 1981.