A Hypothetical Fixation System Capable of Extending Foveation in Congenital Nystagmus

JONATHAN B. JACOBS[a,c] AND LOUIS F. DELL'OSSO[a,b,c]

Ocular Motor Neurophysiology Lab, VAMC[a] and Departments of Neurology[b] and Biomedical Engineering,[c] Case Western Reserve University, Cleveland, Ohio 44106, USA

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INTRODUCTION

Good visual acuity in the presence of the high-velocity oscillations of pendular nystagmus requires that the ocular motor system be capable of reliable and repeatable foveation of the target. The ability of the ocular motor system to acquire a target, despite these ongoing oscillations, requires seamless interaction between the smooth pursuit (SP) and saccadic subsystems. In a previous model[1] we proposed that this cooperation is mediated by the "internal monitor" (IM), a hypothetical grouping of functions that calculates the necessary control signals based on efference copy of position and velocity commands issued by the ocular motor system (OMS). Here we extend this model, adding the ability to extend foveation duration beyond the period of low-velocity motion that occurs naturally at the reversal of eye direction during pendular waveforms.

MATERIALS AND METHODS

The model was designed and implemented using the Simulink component of MATLAB (The MathWorks, Natick, MA). The model is of modular, hierarchical design. The SP subsystem is based on Robinson,[2] chosen for its relative simplicity and ability to be induced into instability, yielding a sinusoidal oscillation characteristic of pendular nystagmus. The saccadic system was based around a resettable neural integrator[3,4] (RNI) with pulse-height and -width nonlinearities. The RNI is part of the circuit that determines saccade duration; when the RNI resets, the saccade ends.

The IM, which is the "brains" of the model, has a long history in ocular motor models.[3–8] The IM makes use of visual signals from the retina, as well as position and velocity efference signals available in the brainstem, to reconstruct and properly respond to changes in target position and velocity. It can then use this information to coordinate interaction between the SP and saccadic and fixation subsystems, despite

Address for correspondence: Jonathan B. Jacobs, Ph.D., Ocular Motor Neurophysiology Lab (W151), Louis Stokes Cleveland VA Medical Center, 10701 East Blvd., Cleveland, OH 44106. Voice: 216-421-3224; fax: 216-231-3461.
jxj24@po.cwru.edu

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the confounding "noise" of the nystagmus. The operational details of these systems can be found elsewhere.[9]

We then tested two separate designs for fixation subsystems. The first approach calculated a "counter-signal," based on the reconstructed nystagmus oscillation, to be summed destructively with (i.e., subtracted from) the commands sent by the SP subsystem to the OMN. The second approach also relied on the reconstructed nystagmus signal, using it as a variable gain to modulate the SP commands to the OMN. After these separate fixation systems were tested in isolation, they were integrated into the full model to determine whether they could utilize position and velocity efference signals to extend foveation.

RESULTS

FIGURE 1 shows the difference between model output for the pseudopendular with foveating saccades (PP_{fs}) waveform when the counter-signal fixation system is disabled (A) and enabled (B). Compare the portion of the slow phase immediately following the foveating saccade (arrow). Without the effect of the fixation system, eye velocity is below 4°/sec for only 18 msec. When fixation is enabled, that duration rises to 40 msec, consistent with better visual acuity. Also, eye position is noticeably

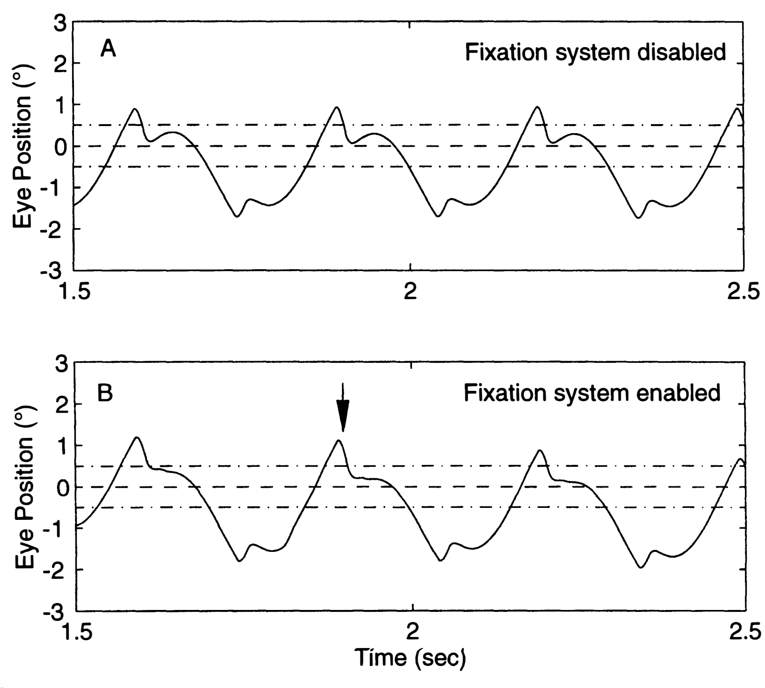

FIGURE 1. Difference between model output for the pseudopendular with foveating saccades (PP_{fs}) waveform when the counter-signal fixation system is disabled **(A)** and enabled **(B)**. Compare the portion of the slow phase immediately following the foveating saccade (*arrow*).

more constant during the period of low velocity when the fixation system is active. Note that the slow phase following the leftward, or braking, saccades is not affected by the fixation system, consistent with actual patient data, indicating that the effort of foveation is a necessary condition for fixation extension.

CONCLUSIONS

Comparative testing of the two possible fixation system designs that we examined favors the counter-signal approach over that of variable gain, as the latter can adversely affect legitimate pursuit signals passing through the OMN, whereas the former acts to remove only the nystagmus oscillation, leaving the true pursuit commands intact. Therefore, the model provides a possible mechanism for a fixation system that acts effectively in the presence of the high-velocity oscillations of the smooth pursuit system typical in CN, slowing the eye sufficiently so that a more useful period of low-velocity foveation is available to the visual system, allowing for greater visual acuity.

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