Leaky Neural Integration Observed in Square-wave Jerks

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Purpose: To clarify the neuronal mechanism for the square-wave jerks (SWJs).

Methods: A 66-year-old man presented with oscillatory eye movements. He showed horizontal nystagmus in rightward gaze and SWJs during fixation at straight ahead. We recorded his eye movements with search coil methods and quantitatively analyzed them.

Results: Visually guided rightward saccades were followed by exponential drifts with average time constants of 0.3–1.0 second, indicating a leaky rightward velocity-to-position integrator. Amplitude of SWJs ranged from 0.5 to 2.5º and average intersaccadic interval was 0.2 seconds. In addition, exponential drifts similar to those observed after visually guided saccades were observed in the SWJs. Rightward fast eye movements of SWJs were followed by exponential drifts lasting for 0.2 seconds with average time constant ($\pm$ SD) of 0.7 $\pm$ 0.3 seconds.

Conclusions: Position signals after visually guided saccades and SWJs were outputs of the identical velocity-to-position integrator. SWJs are generated by the neural circuits involving a pulse generator and a velocity-to-position integrator. **Jpn J Ophthalmol 2003;47:535–536** © 2003 Japanese Ophthalmological Society

Key Words: Neural integrator, saccadic intrusion, saccadic oscillation, square-wave jerks, velocity-to-position integrator.

Introduction

Square-wave jerks (SWJs) are the most common saccadic intrusions.[1,2] Inappropriate fast small eye movements interrupt steady fixation by taking the visual axis away from the target and then returning it approximately 200 milliseconds later. Although the origin of SWJs is unknown, and they have not yet been attributed to any specific part of the brain, eye velocity signals and following eye position signals of SWJs have been suggested to be the outputs of the burst generator and neural integrator, respectively, of the saccadic system.[2] To clarify the origin of the eye position signals of the SWJs, we investigated a patient with SWJs and a unilateral horizontal leaky velocity-to-position neural integrator.[3]

Materials and Methods

The 66-year-old man was referred to the Sapporo Medical University Hospital because of oscillatory eye movements. He had a 13-year history of dysarthria and left hemiplegia due to infarctions in the region of the right basal ganglia, and a 1-year history of dizziness and right hemiplegia due to multiple infarctions in the bilateral cerebral cortex, the left basal ganglia, the left brachium pontis, and the left cerebellar cortex. Results of visual acuity, pupillary responses, intraocular pressure, and ophthalmoscopic examinations were normal in both eyes. Slit-lamp examination showed incipient cataract in both eyes. After receiving the patient's informed consent, we recorded the eye movements of both eyes using the magnetic search coil system (System S3020, Skalar Medical B.V., The Netherlands).

Results

SWJs were observed during steady fixation at straight ahead and became square-wave oscillations[4] with a continuum of SWJs during very slow horizontal and vertical pursuit eye movements (Figure 1). Amplitude of SWJs ranged from 0.5 to 2.5º and average intersaccadic interval (± SD) was 0.2 ± 0.05 (N = 50) seconds. Visually guided horizontal saccade paradigms revealed asymmetrical leakiness in the velocity-to-position integrator (Figure 2A). Postsaccadic exponential drifts indicating leaky integration were clearly observed after rightward saccades but not observed after leftward saccades. Average time constants (± SD) were 0.5 ± 0.1 second (N = 11) and 1.0 ± 0.3 second (N = 9) for target steps of 10º and 20º, respectively. Similar asymmetry of position integration was observed in the SWJs (Figure 2B). Exponential drifts were observed after rightward fast eye movements. Average time constant of exponential drifts observed in SWJs (± SD) was 0.7 ± 0.3 seconds (N = 20). Similar exponential drifts were also observed in square-wave oscillations (Figure 1).

Discussion

The burst generator for horizontal saccades made the fast eye movements of SWJs because their main-

Figure 2. (**A**) Overlaid horizontal visually guided saccades synchronized by the onset of saccades. Postsaccadic exponential decays were observed in the rightward saccades only. (**B**) Overlaid square-wave jerks synchronized by the onset of fast eye movements. Exponential decays similar to that in (**A**) were observed after rightward fast eye movements.

sequence was identical to that of visually guided saccades. In our patient with a unilateral leaky neural integrator, the eccentric eye position of the SWJs and the postsaccadic eccentric eye position showed leaky velocity-to-position integration with similar time constants on the same side. Both position signals are presumably outputs of the identical velocity-to-position integrator.

The most conventional classification of saccadic intrusions depends on the existence of intersaccadic intervals.[5] Our results suggest that SWJs are saccadic intrusions generated by the neural circuit involving a pulse generator and velocity-to-position integrator.
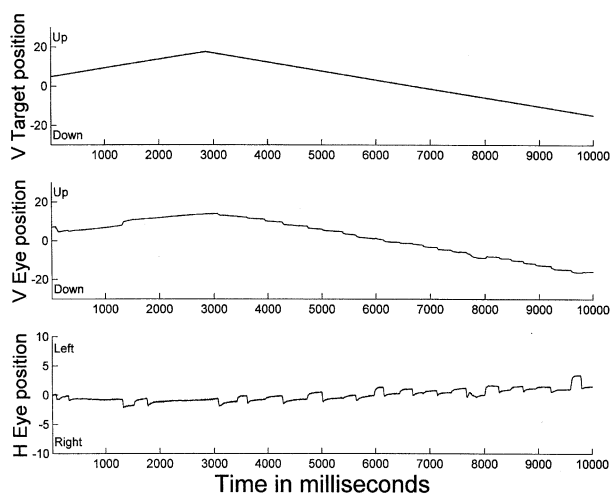

Figure 1. Recordings of saccadic eye movements in 66-year-old man with long history of oscillatory eye movements. Square-wave jerks observed during vertical smooth pursuit eye movements with the target velocity of 5º/s. Abscissa is in milliseconds. Ordinates of each subfigure are in degrees. Top: Vertical target position. Middle: Vertical eye position. Bottom: Horizontal eye position.
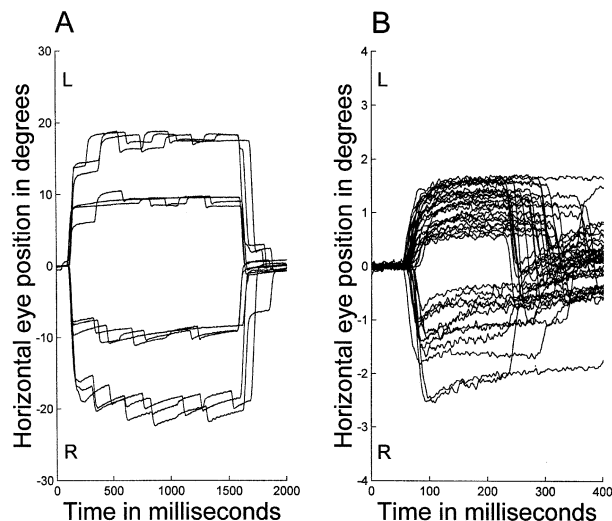
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