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Multiple double saccadic pulses occurring with other saccadic intrusions and oscillations

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ABSTRACT. The ocular motility of a patient with a unique combination of ocular oscillations was studied. He exhibited saccadic overshoot dysmetria, flutter, flutter dysmetria, macro saccadic oscillations and two types of saccadic intrusions: square wave jerks and double saccadic pulses. Frequently the latter intrusion occurred in bursts (multiple double saccadic pulses), a previously unreported finding. The ocular motor control system implications of these eye movements are discussed.

Key words: double saccadic pulse; saccadic intrusion; saccadic oscillation; square-wave jerk

INTRODUCTION

Ocular dysmetria (D)** is an oscillation at the termination of an overshooting refixation saccade with subsequent overshooting saccades of diminishing amplitudes until the eyes come to rest on the target (Selhorst *et al.*, 1976); after each saccade a latency of the visual reaction time occurs before the next opposing saccade. *Ocular flutter* (F) describes the interruption of fixation by bursts of high frequency saccadic oscillations, alternating in direction without intersaccadic intervals (Zee & Robinson, 1979). *Flutter dysmetria* (FD) is ocular flutter occurring immediately after a refixation saccade (Daroff & Dell'Osso, 1979; Zee & Robinson, 1979). *Macro saccadic oscillations* (MSO) consist of sequential, opposing saccades, with normal intersaccadic latencies, which gradually increase and then decrease in amplitude (Selhorst *et al.*, 1976b; Dell'Osso *et al.*, 1977). *'Saccadic intrusions'* (SI) is a generic term which includes several non-repetitive, saccadic interruptions of fixation (Daroff, 1977). The most common intrusion, square wave jerks (SWJ), are paired saccades away from and

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** Abbreviations: *Saccadic intrusions and oscillations:* D - ocular dysmetria; DSP - double saccadic pulse; F - ocular flutter; FD - ocular flutter dysmetria; MSO - macro saccadic oscillations; SI - saccadic intrusions; SP - saccadic pulse; SWJ - square wave jerk. *Saccadic metrics:* HO - hypometric; HR - hypermetric; O - orthometric. *Saccadic trajectories:* do - dynamic overshoot; n - normal; o - overshoot; u - undershoot.

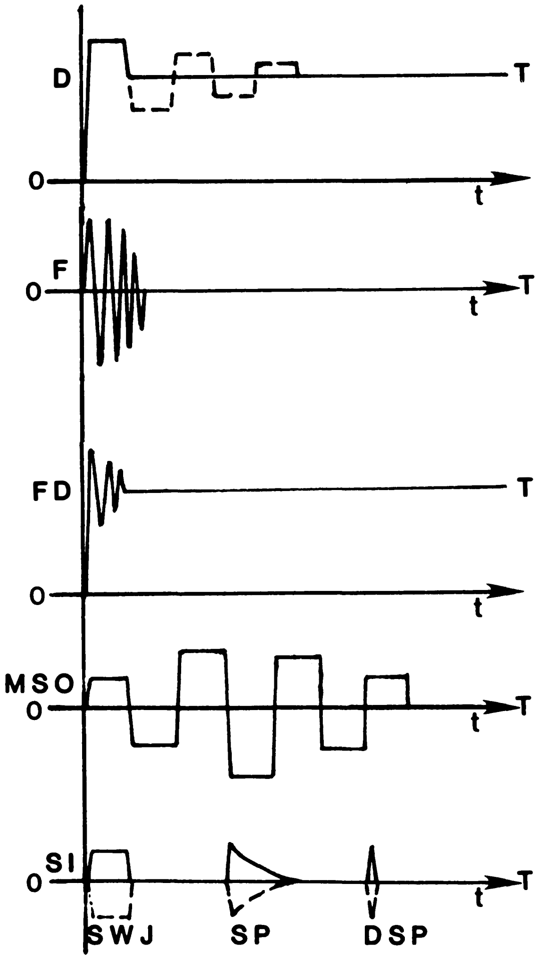


Fig. 1. Schematic illustrations of dysmetria (D), flutter (F), flutter dysmetria (FD), macro saccadic oscillations (MSO) and the saccadic intrusions (SI): square wave jerks (SWJ), saccadic pulses (SP) and double saccadic pulses (DSP). T — target, O — primary position and t — time.

back to the target separated by approximately 200 msec. Other saccadic intrusions include saccadic pulses (SP), which were originally called, 'stepless saccades' (Daroff & Dell'Osso, 1976), and double saccadic pulses (DSP) (Dell'Osso, 1980, 1982; Schmidt *et al.,* 1980). Fig. 1 illustrates the above eye movements. Note the basic difference in timing between saccades; in D, MSO, SWJ and SP saccades are separated by the visual reaction time (150-400 msec) while in F, FD and DSP they are back-to-back (*i.e.,* no latency). We are herein reporting the first patient documented to have a combination of these signs and discussing the ocular motor control system implications of our findings.

CASE REPORT

A 37-year old white man was asymptomatic until February 1979 when he noticed episodic visual blurring after he moved his eyes or concentrated intently visually. He had a slight tendency to fall to the left and occasional light-headedness. The problem persisted and in May, 1979 he was evaluated at his hospital. Neurological examination was normal except for an ocular oscillation. CT scan, skull X-rays and routine laboratory studies were normal. CSF examination revealed a total protein of 39 mg % with a gamma globulin fraction representing 10 mg % or 26% of the total; the upper limit of normal for that laboratory was 12% of the total. A brainstem auditory evoked response was normal but visual evoked potentials, using both flash and pattern stimuli, revealed a prolongation of the latency of the first wave of the left eye as compared to the right; the absolute latencies were within normal limits for the laboratory, however. Because of the ocular oscillation and the abnormal CSF, a diagnosis of multiple sclerosis was highly suspected. The patient was referred to our laboratory on October 25, 1979. His symptoms of oscillopsia had persisted. Repeat neurological evaluation, exclusive of the eye movement examination, was normal except for: difficulty with tandem gait, slight finger-to-nose and heel-to-shin

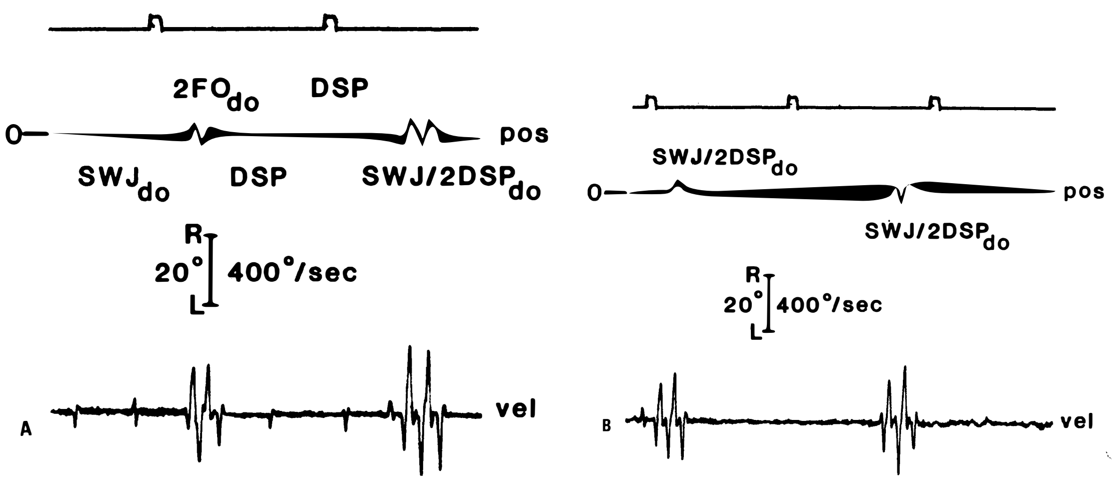


Fig. 2. Saccadic intrusions which interrupted steady gaze in the primary position. (A) A square wave jerk with dynamic overshoot trajectory (SWJ$_{do}$), two cycles of flutter followed by an orthometric saccade with dynamic overshoot trajectory (2FO$_{do}$), a double saccadic pulse (DSP), a double saccadic pulse (DSP) and a combination of a square wave jerk and two double saccadic pulses with dynamic overshoot trajectories (SWJ/2DSP$_{do}$). (B) Both intrusions consisted of a square wave jerk (SWJ) interrupted by two double saccadic pulses with dynamic overshoots (2DSP$_{do}$). In this, and subsequent figures, eye position is indicated by pos, velocity by vel, timing marks indicate 1 sec intervals and primary position is indicated on the position trace by a zero. All saccadic intrusions shown were conjugate.

ataxia, and a suggestive right Babinski sign. Clinical evaluation of his eye movements disclosed a flutter-like oscillation in primary position which interrupted straight ahead fixation as well as an oscillation following each saccadic eye movement which was interpreted as ocular dysmetria. He was then studied with quantitative oculography.

METHODS

Ocular motility was recorded utilizing a Narco Biosystems infrared system and a modified Beckman Type-R rectilinear Dynograph. The complete system bandwidth was DC-100 Hz (eye position and velocity). The patient was seated at the center of a 1.14 m arc which contained red light-emitting diodes as targets; the head and chin were stabilized.

RESULTS

With straight ahead gaze there were occasional square wave jerks (SWJ) and brief flutter-like movements consisting of flutter (F) and double saccadic pulses (DSP) (Fig. 2A) or SWJ-like movements combined with DSP (Fig. 2B). Fixation was often interrupted by bursts of DSP which were separated by approximately 40-100 msec. In this patient, the saccades contained in the DSP usually had dynamic overshoots (hence, DSP$_{do}$) and often multiple DSP interrupted a SWJ (hence, SWJ/2DSP$_{do}$).* As

* The nomenclature used to describe the various eye movements shown in this paper was developed by Schmidt *et al.* (1980). It allows an accurate description of both the static metrics and dynamic trajectories of saccadic movements without the ambiguity inherent in previously used terminology.

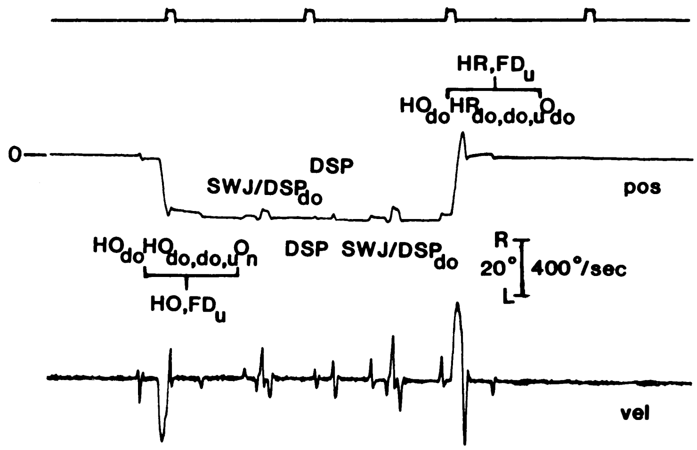


Fig. 3. A refixation from primary position to 20° to the left steady gaze at 20° to the left and a refixation back to primary position. The first refixation is accomplished by a hypometric saccade with a dynamic overshoot, another hypometric saccade with two dynamic overshoots on an undershooting trajectory and an orthometric saccade with a normal trajectory (HO_{do}-$HO_{do,do,u}O_n$). The back-to-back dynamic overshoots constitute one cycle of flutter dysmetria (HO,FD_u). Steady fixation at 20° to the left was interrupted by a square wave jerk containing a double saccadic pulse with dynamic overshoot trajectory (SWJ/DSP_{do}), a double saccadic pulse (DSP), a double saccadic pulse (DSP) and another square wave jerk containing a double saccadic pulse with dynamic overshoot (SWJ/DSP_{do}). The refixation back to primary position was accomplished by a hypometric saccade with dynamic overshoot, a hypermetric saccade with two dynamic overshoots on an undershooting trajectory and an orthometric saccade with normal trajectory ($HO_{do}HR_{do,do,u}O_n$). Again, the two back-to-back dynamic overshoots constitute one cycle of flutter dysmetria (HR,FD_u). What appear to be discrete decelerations in some velocity traces in this and other figures are actually a reflection of spurious 60 Hz noise present when this patient was recorded.

an example, in Fig. 2B, each of the two saccadic intrusions consisted of a rightward-starting SWJ, interrupted by two leftward DSP with dynamic overshoots and ending with the leftward return saccade of the SWJ (Figs. 2A and 2B). The total amplitude was approximately 5-8° and the duration of the period during which the eyes had zero velocity was 40-100 msec. During refixations between center gaze and ±20°, the saccades were frequently hypermetric (HR) and were followed by combinations of dynamic overshoots (do), dysmetria, flutter dysmetria (FD), and/or MSO. Fig. 3 illustrates both hypometric (HO) and hypermetric (HR) saccades followed by dynamic overshoots superimposed on undershooting trajectories. After a latency of about 200 msec a small, orthometric (O) saccade returned the eye to the target. The eyes were on target most of the time (approx. 1.75 sec) until the next refixation except for a few brief bursts of a combination of SWJ/DSP and DSP similar to those in Fig. 2.

Fig. 4 illustrates a refixation from 20° left to center gaze. After the initial hypermetric saccade and its dynamic overshoot (HR_{do}), there was a latency of about 40 msec followed by two DSP with do. The DSP were followed by periods during which the eye remained motionless and slightly beyond the target. Each of the return sac-

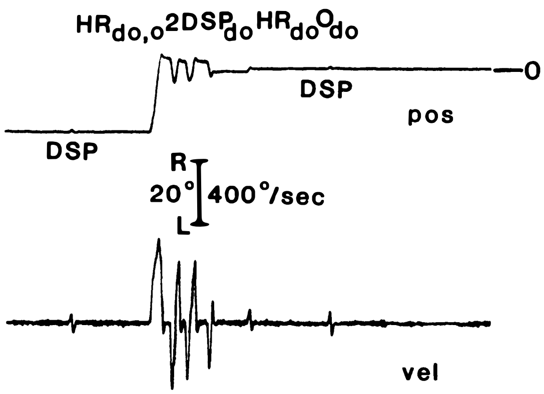


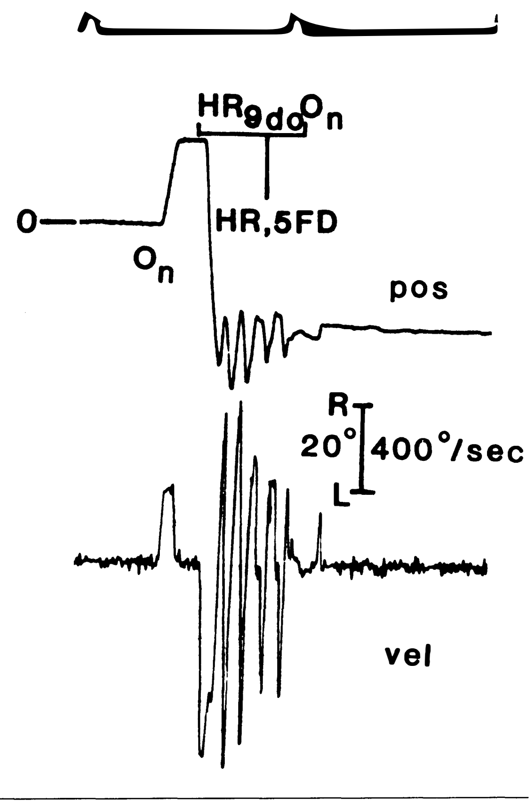
Fig. 4. A double saccadic pulse (DSP) during fixation at 20° left gaze. A refixation from 20° left to primary position consisting of a hypermetric saccade with a dynamic overshoot on an overshooting trajectory, two double saccadic pulses with dynamic overshoots, a hypermetric saccade with a dynamic overshoot and an orthometric saccade with a dynamic overshoot ($HR_{do,o}2DSP_{do}HR_{do}O_{do}$). This was followed by a double saccadic pulse (DSP).

cades in the DSP had a small dynamic overshoot (1°) prior to this motionless period. The eye finally reached the target by a HR_{do} and an O_{do} saccade, spaced apart by approximately 200 msec. Of note was that every saccade, large or small, had conjugate dynamic overshoots and the DSP were predominantly composed of leftward followed by rightward saccadic pairs.

Fig. 5 shows FD of the left eye occurring immediately after a refixational saccade from +20° to −20° (*i.e.,* right to left). The first few cycles of FD were clearly large dynamic overshoots but the last two cycles appeared similar to those shown in Fig. 2. Parts of the *position* recording appeared to be flat, but the *velocity* recording showed that at no time was the velocity truly zero. After the latency of about 180 msec, a small rightward saccade returned the eye back to the target (O_n).

Fig. 6 shows one DSP (or two do) occurring after attempted refixation from center to −20°; this constitutes FD. Although the eye quickly (≃150 msec) stabilized on the target, another DSP occurred 200 msec later. The eye remained on target, most of the time until the next refixation, except for a few brief saccadic intrusions similar to

Fig. 5. Flutter dysmetria (FD) following a leftward saccade. After an orthometric rightward saccade with normal trajectory (O_n) the leftward saccade consisted of a hypermetric saccade with a string of nine dynamic overshoots (*i.e.,* five cycles of flutter dysmetria) and an orthometric saccade with normal trajectory ($HR,5FD,O_n$).



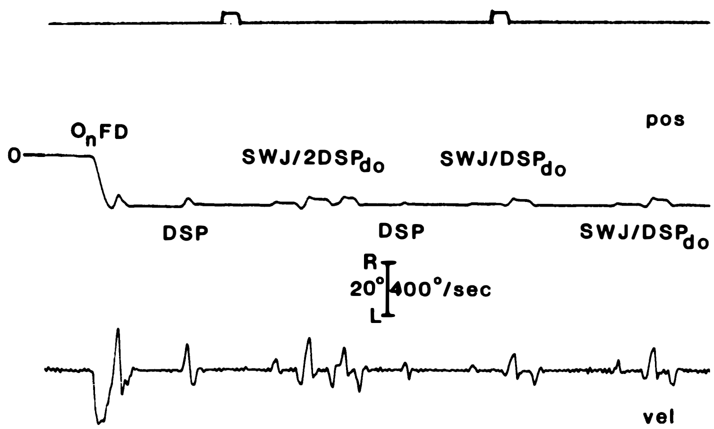
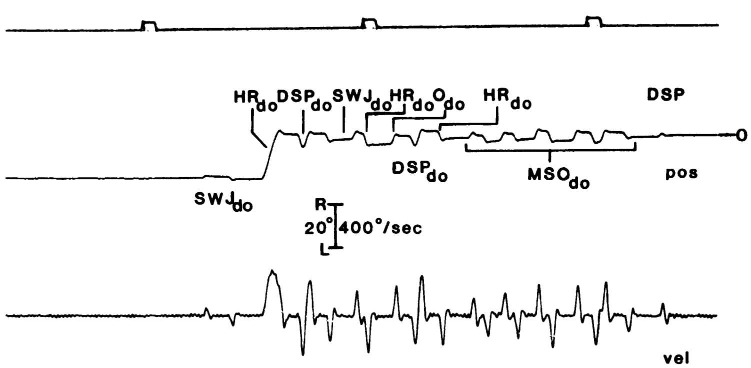


Fig. 6. A brief burst of flutter dysmetria (FD) followed by saccadic intrusions during steady gaze 20° to the left. The leftward refixation was accomplished by an orthometric saccade with normal trajectory followed by a double saccadic pulse, which constituted the FD (O_n, FD). Steady fixation was interrupted by a double saccadic pulse (DSP), a square wave jerk interrupted by two double saccadic pulses with dynamic overshoots ($SWJ/2DSP_{do}$), a double saccadic pulse (DSP), another square wave jerk interrupted by a double saccadic pulse with dynamic overshoot (SWJ/DSP_{do}) and a third square wave jerk interrupted by a double saccadic pulse with dynamic overshoot (SWJ/DSP_{do}).

those shown in the previous figures.

Fig. 7 shows a hypermetric saccadic refixational movement with a long string of subsequent intrusions, hypermetrias and oscillations consisting predominantly of SWJ, DSP_{do}, HR and a burst of MSO movements, with inter-saccadic latencies of 60 to 100 msec. All the saccadic movements contained dynamic overshoots.

Fig. 7. Saccadic intrusions, hypermetria and macro saccadic oscillations following a refixation back to primary position. Prior to the refixation, a square wave jerk with dynamic overshoot is shown (SWJ_{do}). The refixation was accomplished by a hypermetric saccade with dynamic overshoot (HR_{do}) which triggered a double saccadic pulse with dynamic overshoot (DSP_{do}), a square wave jerk with dynamic overshoot (SWJ_{do}), a hypermetric saccade with dynamic overshoot (HR_{do}), an orthometric saccade with dynamic overshoot (O_{do}), a double saccadic pulse with dynamic overshoot (DSP_{do}), a hypermetric saccade with dynamic overshoot (HR_{do}), a string of macro saccadic oscillations with dynamic overshoots (MSO_{do}) and a double saccadic pulse (DSP).



DISCUSSION

This patient always exhibited an ocular instability following saccadic refixations and occasionally when attempting to maintain steady gaze on a target. When refixating, the eyes usually overshot the target with a subsequent dynamic overshoot and then, either burst into a few beats of flutter dysmetria (FD) (Figs. 3, 5, and 6) or into several beats of peculiar combinations of FD, multiple double saccadic pulses (DSP), and macro saccadic oscillations (MSO) (Figs. 4 and 7). Combination SWJ/DSP movements also occurred spontaneously during steady gaze. Every saccadic movement was followed by one or, sometimes, several dynamic overshoots.

The frequent dynamic overshoots and the flutter were similar to those reported by Zee & Robinson (1979). There are pause cells in the brainstem that fire continuously except during saccades, when they cease firing (pause). By reducing the pause cell bias, the Zee-Robinson model showed a refixation with (a) no, (b) one, or (c) any number of dynamic overshoots resulting in flutter. That is, flutter shares the same basic mechanism as a dynamic overshoot or a DSP. These authors assumed that fluctuations in the level of the pause cell bias caused intermittent spontaneous oscillations.

Some of the apparent MSO occurring between single bursts of flutter were peculiar because the latencies were shorter than the visual reaction time, their cycles were interspersed with flutter, and their amplitudes were fairly constant during each burst (*i.e.,* not increasing and decreasing). The shorter latencies of these movements could be due to a non-visually-evoked reflex similar to macro square wave jerks (Dell'Osso *et al.,* 1975, 1977). Both MSO and saccadic overshoot dysmetria are thought to be due to a cerebellar ocular motor disorder (Selhorst *et al.,* 1976a, 1976b). Flutter dysmetria is thought to result from malfunctions of the saccadic pulse generator neural circuitry (Zee & Robinson, 1979). The timing of saccades in MSO, D and SWJ is the same and each saccade is complete (*i.e.,* the result of a pulse and step of neural innervation). This is in contrast to F, FD and DSP where saccades are back-to-back and caused by only a pulse of innervation. These two distinct classes of saccadic pathology suggest malfunctions at different levels in the ocular motor system. Both MSO and D are due to a saccadic gain greater than one. The saccadic intrusion, SWJ, is due to a spurious error signal which takes the eyes off target creating a real error which is reflexively corrected by a return saccade after a normal latency. F, FD and DSP are best understood as pause cell instabilities in the pulse generator itself.

Voluntary nystagmus was part of the initial differential diagnosis in our patient. This oscillation (Shults *et al.,* 1977) consists of rapidly alternating small-amplitude saccades, as in ocular flutter. It was modelled by Zee & Robinson (1979) as an inhibition of the pause cells, similar to the model simulation of dynamic overshoots.

The patient we studied with presumed multiple sclerosis manifested an undocumented eye movement abnormality — multiple DSP. In addition, he had saccadic overshoot dysmetria, flutter, flutter dysmetria, macro saccadic oscillations, and square wave jerks reflecting cerebellar, and possibly co-existing brainstem dysfunction. Their presence in the same patient allows comparisons concerning their occurrence and interrelationships not previously possible. Specifically, we were able to observe the interaction between DSP, F or FD and SWJ (during fixation) or O or HR saccades (during a refixation). The former intrusions and oscillations caused delay in the corrective saccades of SWJ or HR until the pause cell dysfunction was completed. Thus, if the eyes were taken off target by a saccade (the beginning of a SWJ) and several DSP or F occurred, the return saccade of the SWJ was delayed until the pulse generator instability ended. What resulted were the SWJ/DSP type intrusions documented in this report. The implication of this interaction is that while the pulse generator instabilities are caused by pause cell bias dysfunction, SWJ are due to an extra-pulse generator dysfunction in the error signal which is its input. Thus, SWJ and HR require some latency between saccades since they are responses of a normal pulse generator, with its associated latency, to an erroneous input but DSP, F and FD do not. If the latter are triggered by the error-producing first saccade of a SWJ or by an HR saccade, the corrective second saccade must still be made once the pulse generator oscillations cease. Such complex and variable eye movement disturbances can only be elucidated with quantitative oculography and careful analysis of the recording.

REFERENCES

DAROFF, R. B.: Ocular oscillations. *Ann. Otol. 86*:102-107, 1977

DAROFF, R. B. & DELL'OSSO, L. F.: Nystagmus – A contemporary approach. In: *Topics in Neuro-Ophthalmology* (H. S. Thompson, R. B. Daroff, J. S. Glaser, L. Frisen and M. D. Sanders, eds.), pp. 286-297. Williams and Wilkins Company, Baltimore 1979

DAROFF, R. B. & DELL'OSSO, L. F.: The control of eye movements. In: *AAN Neurological Reviews, 1976*, pp. 143-170. American Academy of Neurology, Chapter 7, Minneapolis 1976

DELL'OSSO, L. F.: Nystagmus and other ocular motor oscillations. In: *Neuro-Ophthalmology* (S. Lessell and J. T. W. van Dalen, eds.), Vol. I, pp. 146-177. Excerpta Medica, Amsterdam 1980

DELL'OSSO, L. F.: Nystagmus and other ocular motor oscillations. In: *Neuro-Ophthalmology* (S. Lessell and J. T. W. van Dalen, eds.), Vol. II, pp. 148-171. Excerpta Medica, Amsterdam 1982

DELL'OSSO, L. F., ABEL, L. A. & DAROFF, R. B.: 'Inverse latent' macro square wave jerks and macro saccadic oscillations. *Ann. Neurol. 2*:57-60, 1977

DELL'OSSO, L. F., TROOST, B. T. & DAROFF, R. B.: Macro square wave jerks. *Neurology 225*:975-979, 1975

SCHMIDT, D., DELL'OSSO, L. F., ABEL, L. A. & DAROFF, R. B.: Myasthenia gravis: saccadic eye movement waveforms. *Exp. Neurol. 68*:346-364, 1980

SELHORST, J. B., STARK, L., OCHS, A. L. & HOYT, W. F.: Disorders in cerebellar ocular motor control. I. Saccadic overshoot dysmetria and oculographic, control system and clinico-anatomical analysis. *Brain 99*:497-508, 1976a

SELHORST, J. B., STARK, L., OCHS, A. L. & HOYT, W. F.: Disorders in cerebellar ocular motor control. II. Macro saccadic oscillation and oculographic, control system and clinico-anatomical analysis. *Brain 99*:509-522, 1976b

SHULTS, W. T., STARK, L., HOYT, W. F. & OCHS, A. L.: Normal saccadic structure and voluntary nystagmus. *Arch. Ophthal. (Chicago) 95*:1399-1404, 1977

ZEE, D. S. & ROBINSON, D. A.: A hypothetical explanation of saccadic oscillations. *Ann. Neurol. 5*:405-414, 1979