Types of saccadic eye movements

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The term *saccade* is applied to a variety of eye movements, including saccadic refixations, microsaccades, fast phases of nystagmus, and fast phases of other ocular oscillations. Numerous clinical and theoretical descriptions of saccades have resulted in a proliferation of named saccadic subtypes and clinical syndromes; these include purely descriptive phrases and those meant to imply physiology or pathophysiology. Among such terms are *hypometric saccades, dysmetric saccades, glissadic eye movements, slow saccades, overlapping saccades, dynamic overshoots, closely spaced saccades,* and *pulseless saccades* (figure 1). From the analysis of quantitative eye movement recordings of normal individuals and patients with neurologic diseases, and from the results of computer simulations, one may describe saccadic eye movement subtypes based on the responsible neurologic control signals. This description provides a logical framework for clinical observations which we hope will be useful during neurologic examinations.

The organization of figure 1 is based on the underlying neural controller signals. The controller signal has two components: the pulse that moves the eye rapidly from one point to the next, and the step that holds the eye in the new position.[1] The pulse is composed of a high-frequency burst of motoneuron activity for the agonist and a concomitant pulse of inhibition, a pause in motoneuron firing, for the antagonist. The step is composed of step changes in the steady state motoneuron firing rates: a step increase for the agonist and a step decrease for the antagonist. Inhibition of the antagonist is as important as excitation of the agonist for attaining high-velocity saccades.[2]

When both the pulse and the step are the correct size for the desired refixation change, there is a *normometric saccade,* an entirely accurate single-step refixation. When both the pulse and the step are not the correct size, a dysmetric refixation eye movement results.

A common type of saccadic undershoot is the single-step, *hypometric* saccadic refixation. If the step portion of the motoneuron saccadic controller signal is correct, but the pulse portion of the controller signal is too small due to an error, then the dynamic saccade (the initial fast portion of the saccadic eye movement) falls short of the desired position, and the saccadic refixation is completed with a glissadic eye movement. A *glissadic* eye movement is a gliding or sliding eye movement which gradually approaches the target position.[3] This includes any eye movement configuration resulting from a mismatching of the pulse and step components of the controller signal.[4] Saccadic refixations with glissades have been recorded from patients with internuclear ophthalmoplegia, abducens palsy, and myasthenia gravis, and from fatigued normals. A variation of this type of hypometric saccade, with very low velocity, could result from a controller signal with no pulse at all. The resultant eye movements have been referred to as "slow," or "pulseless" saccades and include the eye movements described in spinocerebellar degeneration,[5] progressive supranuclear palsy,[6] and extraocular muscle paralysis.[2] These slow or pulseless saccades are the extreme case of glissadic undershoot, and have velocities similar to vergence eye movements.

Single-step, *hypermetric* saccadic refixations (those which overshoot the target with the dynamic saccade) may have either dynamic overshoot or glissadic overshoot. Normal human saccades often have dynamic overshoot.[7] Monkeys also exhibit dynamic overshoot, but this has been studied only for small saccades.[8] Glissadic overshoot is caused by a mismatch between the pulse and step components of the controller signal.[4] When the step is correct and the pulse is too big, the error is probably created by a pulse of too long a duration.[4]

Multiple-step dysmetric saccadic refixations are composed of two or more dynamic saccadic compo-

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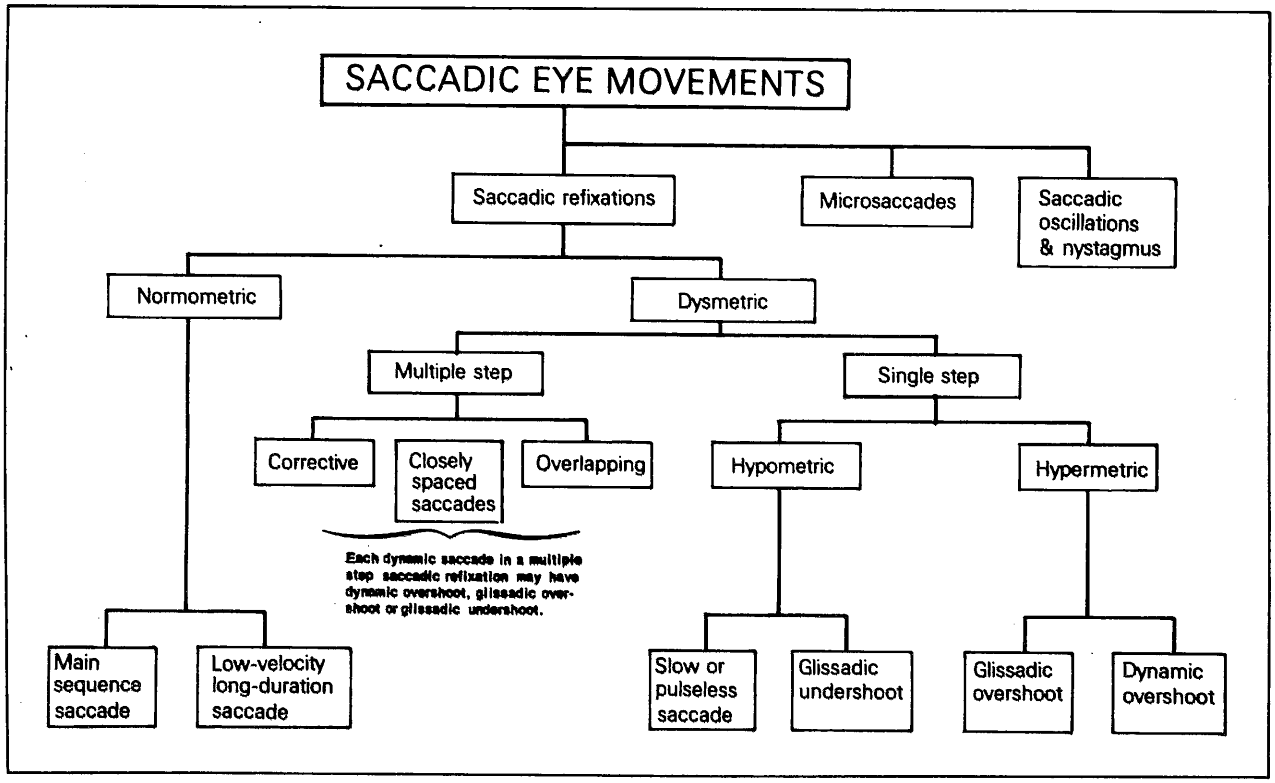


Figure 1. Interrelationships of saccadic eye movement subtypes.

nents and include movements with corrective saccades, closely spaced saccades, and overlapping saccades. The corrective saccades normally have an intersaccadic interval of about 150 msec. There is adequate time for them to be a result of processing of feedback information. When a subject anticipates the target movement and moves his eyes before the target moves, saccadic refixations with multiple corrective saccades are common. When the intersaccadic interval becomes roughly 100 msec or less, it becomes unlikely that visual feedback is involved. Therefore, the control strategy is different and the resulting multiple step refixation has closely spaced saccades. These closely spaced saccades are common in normals,[9] but excessive occurrences may be indicative of pathology.[10] As the intersaccadic interval gets smaller and smaller, the velocity profiles of the saccades begin to overlap, and overlapping saccades are usually signs of fatigue.[9]

The phrase *multiple-step saccadic refixation* has been used to describe eye movements composed of multiple dynamic saccades.[10] This term is preferable to the term *hypometric,* which implies that the individual segments have particular characteristics that are usually not apparent clinically. Multiple-step saccadic refixations consist of multiple dynamic saccades and thus consist of multiple saccadic pulses and multiple saccadic steps. Therefore, the term *multiple-step* is just as descriptive as multiple-pulse saccadic refixations.

The term *hypometric saccade* is limited, therefore, to single-step saccades in which the eye undershoots the target. The phrases "hypometric refixation" and "hypometric saccade" have been used to describe fragmented or "stepwise" saccadic refixations. This usage is ambiguous because it refers not only to the individual saccadic components, but to the entire refixation. Hence, it would be more appropriate and accurate to refer to such fragmented refixations as multiple-step saccadic refixations, the refixation pattern commonly seen in patients with cerebellar system disease and progressive supranuclear palsy.[6]

Most of the saccadic eye movement subtypes may be seen at the bedside. Glissadic adduction undershoot in internuclear ophthalmoplegia is a good example. Quantitative eye movement recordings have allowed certain saccadic abnormalities to be documented and defined. The analysis of these recordings should provide an understanding that can help the physician to refine the clinical examination and observe such defects during refixations between stationary targets, e.g., the examiner's nose and outstretched finger. Dynamic overshoot and subtle low-velocity, long-duration saccadic adaptations are evident only with refined recording techniques. However, multiple-step refixations are easily observed, for example, in progressive supranuclear palsy and

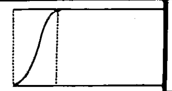
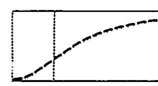
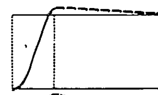
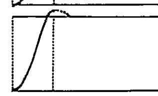
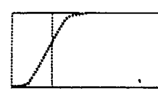
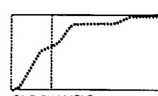
SACCADIC REFIXATION	EQUIVALENT and or COMMON TERMS	COMPOSITION	CONTROLLER SIGNALS	ILLUSTRATION	CLINICAL CORRELATION
1. Normometric	Accurate On Target Main Sequence	Dynamic Saccade—	Correct		Normal
2. Glissadic Undershoot	Undershoot Drifting Gliding	Hypometric Dynamic Saccade— + Glissade---	Pulse Too Small Step Correct		Nerve or Muscle Paresis Fatigue Internuclear Ophthalmoplegia Myasthenia
3. Pulseless	Substituted Pursuit Hypometric Slow	Glissade ---	No Pulse Step Correct		Spinocerebellar Degeneration
4. Glissadic Overshoot	Overshoot Hypermetric	Hypermetric Dynamic Saccade— + Glissade---	Mismatched Pulse and Step		Abductor Overshoot in Internuclear Ophalmoplegia
5. Dynamic Overshoot	Overshoot Hypermetric	Dynamic Saccade — Return Saccade —	Specialized		Normal
6. Low-Velocity Long-Duration	Slow	Adapted Saccade ——	Low Height Long-Duration Pulse		Progressive Supranuclear Palsy Wilson's Disease Huntington's Chorea
7. Multiple Step	Hypometric Fragmented	Combinations —— of 1-6 Above	Multiple Pulse-Step Controller Sequences	 ONE EXAMPLE	Cerebellar Disease Drug Intoxication Fatigue Brainstem Dysfunction

Figure 2. Saccadic refixation subtypes (column 1); equivalent and commonly used terms (column 2); their component eye movements (column 3); their underlying neuronal controller signals (column 4); computer simulations of typical refixations showing eye position as a function of time (column 5); and clinical correlations (column 6). The continuous lines represent the dynamic saccadic components; the dashed lines represent the glissadic components; and the dotted lines represent other eye movement components, such as the return phase of dynamic overshoot. Simulation 1 is of a 15-degree dynamic saccade. The record length is 160 msec. All other simulations have the same scales, except for simulation 3, that of the pulseless saccade, which has a record length of 320 msec.

drug intoxication. This refixation pattern occurs occasionally in normal individuals, but a predominant pattern indicates pathology. Glissadic undershoots may also be seen in patients with peripheral ocular motor nerve paresis and myasthenia gravis. Pulseless saccades are apparent in patients with spinocerebellar degeneration. Observations of these saccadic abnormalities are of diagnostic importance.

Based on current understanding of the responsible controller signals, these eye movement terms are organized in figure 2. The names in this figure are taken from the literature, and describe the trajectory of human eye movements that are the results of neurologic control signals. The structure of the figure is based on computer simulations of these signals, the presumed causes of the eye movements. Some of the clinical conditions in which the saccadic subtypes occur are tabulated.

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