10. Nystagmus and other ocular motor oscillations and intrusions

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INTRODUCTION

In Volume 1, this chapter (1) contained a definition and at least one relevant reference for each type of nystagmus, saccadic oscillation or saccadic intrusion. Table 1 lists the 41 different types of nystagmus along with 64 other terms found in the literature to describe them; similarly, Table 2 lists the 16 saccadic oscillations and intrusions with 27 other terms found in the literature. These Tables evolved from those which appeared in Volume 2 (2) and contain the following changes: In Table 1, 'ictal' has been included under Epileptic nystagmus; 'monocular fixation' under Latent/Manifest latent nystagmus; 'kinetic', 'optic', 'optomotor', 'panoramic', 'railway', 'sigma', and 'train' under Optokinetic nystagmus. In Table 2, 'dipping' and 'inverse' have been included under Bobbing; 'Double saccadic pulses' replaces Saccadic double pulses; and 'Psychogenic flutter' replaces Voluntary 'nystagmus' as a specific type of saccadic oscillation with 'hysterical flutter' and 'voluntary flutter' added to this category. No doubt this evolution, which has resulted from quantitative oculography, will continue as we learn more. I have developed the definitions and categorizations used herein, and initially presented in Volume 1, by the systematic application of criteria derived from accurate ocular motility recordings made during the past 15 years by other investigators and myself. Such criteria clearly differentiate between nystagmus and other ocular motor oscillations and, as a result, some eye movements described by the word 'nystagmus' were found to be saccadic oscillations. Most oscillations were originally named without the benefits of accurate ocular motor recordings (the naming preceded the understanding). Quotation marks are used for those oscillations that are *not* truly nystagmus or for purely subjective clinical terms found in the literature which are inadequate, not clearly defined, or have been misapplied to several different types of oscillations. Since these ambiguous and/or erroneous terms do not convey accurate information about the basic nature of the movement, they are better left at the bedside and not imposed upon the scientific literature. In those cases where historical precedence supports their continued usage (convergence-retraction 'nystagmus'), the quotation marks indicate that these are non-nystagmic oscillations (i.e. saccadic). I hope, for the reader's sake, that future investigators will be more reluctant to use subjective clinical expressions to describe oscillating eyes, and will take more care to identify properly an oscillation as one of the main (numbered) types listed in Tables 1 and 2. Obviously, this can only be

TABLE 1. *Nystagmus*

1. Abduction
   'ataxic'
2. Acquired
   fixation
3. Arthrokinetic
   induced
4. Audiokinetic
   induced
5. Bruns
6. Centripetal
7. Cervical
   neck torsion
   vertibral-basilar artery insufficiency
8. Circular/Elliptic/Oblique
   alternating windmill
   circumduction
   diagonal
   elliptic
   gyratory
   oblique
   radiary
9. Congenital
   fixation
   hereditary
10. Convergence
11. Convergence-evoked
12. Dissociated
    disjunctive
13. Downbeat
14. Drug-induced
    barbiturate
    induced
15. Epileptic
    ictal
16. Flash-induced
    flicker-induced
    induced
17. Gaze-evoked
    gaze-paretic
    deviational
18. Horizontal
19. Induced
20. Intermittent vertical
21. Jerk
22. Latent/Manifest latent
    manifest latent
    monocular fixation
23. Lateral medullary
24. Lid
25. Miner's*
    occupational
26. Muscle-paretic
    myasthenic
27. Optokinetic
    induced
    kinetic
    optic
    optomotor
    panoramic
    railway
    sigma
    train
28. Optokinetic after-
    induced
    post-optokinetic
    reverse post-optokinetic
29. Pendular
30. Periodic/Aperiodic alternating
    alternans
31. Physiological
    end-point
    fatigue
32. Pursuit after-
    induced
33. Pursuit-defect*
34. Rebound
    induced
35. See-saw
36. Spontaneous
37. Torsional
    rotary
38. Uniocular
39. Upbeat
40. Vertical
41. Vestibular
    ageotropic
    alternating current
    caloric
    caloric after-
    compensatory
    electrical
    faradic
    galvanic
    geotropic
    head-shaking
    induced
    labyrinthine
    perverted
    pneumatic/compressive
    positional/alcohol
    positioning
    postrotational
    pseudocaloric
    rotational/perrotary
    secondary phase

* may not exist.

done with accurate eye movement recordings as a basis. If recordings reveal a truly new type of oscillation, the name chosen should be descriptive of the actual recorded eye movement and not the bedside impression. It would be helpful if the terms used reflected the mechanism thought to be responsible for the eye movement (e.g. saccadic pulse); such names maximize the information carried to the reader and clearly describe a movement by its well-defined component parts.

Failure to recognize the inaccuracies of clinical descriptions of complex oscillations has resulted in a continuation of the confusion and contradiction which have permeated the nystagmus literature for the past 100 years. Even a trained ophthalmological observer is no more able to characterize properly an ocular motor oscillation by visual inspection alone than a trained cardiologist is able to draw a patient's QRS complex without a good instrument to record it. It is actually unfortunate that the eyes are visible to the investigator, for that has been the single largest impediment to good research in this area. Had they been hidden, like the heart, we would have been much closer to an understanding of ocular motility than we are at present, and perhaps obtaining an ocular motility recording (OMR) would be as familiar to the clinician as an electrocardiogram. I choose not to use the letters 'ENG' (electronystagmography) which, in most cases, has come to represent how not to record ocular motility, i.e. low bandwidth, AC-coupled electro-oculogram (EOG) with bitemporal electrodes and curvilinear recordings. Such recordings are little better than clinical observation alone. Good

TABLE 2. *Saccadic oscillations and intrusions*

1. Bobbing
   dipping
   inverse
2. Convergence-retraction 'nystagmus'
   'nystagmus' retractoris
3. Double saccadic pulses
   saccadic intrusions
4. Dynamic overshoot
   'quiver'
5. Dysmetria
6. Flutter
7. Flutter dysmetria
8. Macro saccadic oscillations
9. Macro square-wave jerks
   Kippdeviatione 'Kippnystagmus'
   'pendular macro-oscillations'
   saccadic 'nystagmus'
10. Myoclonus
    'lightning eye movements'
11. Opsoclonus
    'dancing eyes'
    'lightning eye movements'
    saccadomania
12. Psychogenic flutter
    hysterical flutter
    hysterical 'nystagmus'
    'ocular fibrillation'
    'ocular shuddering'
    psychological 'nystagmus'
    voluntary flutter
    voluntary 'nystagmus'
13. Saccadic lateropulsion
14. Saccadic pulses
    saccadic intrusions
15. Square-wave jerks
    Gegenrücke
    hopping 'nystagmus'
    'lightening eye movements'
    myoclonus
    saccadic intrusions
    Zickzackbewegungen
16. Superior oblique myokymia

recordings require high bandwidth, direct coupling (DC), binocular (not bitemporal) electrodes and rectilinear printout. Infrared reflection and magnetic search coil are more sensitive and more stable methods than EOG, and velocity channels are often an invaluable addition. A blink monitor is also indispensable.

In this Volume, only those specific types of oscillations and intrusions in which noteworthy contributions have been made to the literature in the past 24 months will be discussed. The reader is referred to Volumes 1 and 2 for definitions and discussions of those types for which no recent contributions have been made.

NYSTAGMUS

The word 'nystagmus' is derived from the Greek word νυσταγμός, meaning drowsiness, which in turn is derived from νυσταζειν, meaning to nod in one's sleep. It should be noted that this nodding oscillation is generated and sustained by the slow downward drifting of the head; the upward head jerks are corrective, i.e. they serve to restore upright head posture.

In keeping with this original definition, nystagmus is defined as follows: a biphasic ocular oscillation containing slow eye movements which are responsible for its genesis and continuation. Fast eye movements (saccades), if they are present, serve a corrective function and do not represent the basic ocular motor dysfunction. The two phases of ocular nystagmus are approximately equal in amplitude. This section contains discussions of recent studies of 16 nystagmus types from the 41 originally identified in Table 1; they are in alphabetical order.

Several papers have appeared recently that discuss nystagmus in general. Included are review articles, relationships to clinical diagnosis, and methods of recording and analyzing nystagmus data. A paper on supranuclear and internuclear ocular motor disorders by Kömpf (3) contains an impressive bibliography with 348 entries which should satisfy even the most avid reader. In contrast, a review of nystagmus by Van Vliet (4), while good, is underreferenced. Another excellent review which relates the value of abnormal eye movements to diagnosis is by Leigh and Zee (5). This, and their recent book (6), is recommended to all who are interested in eye movements as they relate to neurological disorders. Kumar (7) sought to determine whether 'spontaneous' nystagmus was a pathological sign. His conclusion was that spontaneous nystagmus in 'normals' should be regarded as an ocular motor abnormality with no detectable cause, whereas in 'patients' it is a valuable diagnostic sign and should be considered significant regardless of its slow phase velocity. Since spontaneous nystagmus is a non-type of nystagmus (all of the non-induced types listed in Table 1 are spontaneous), talk of its significance in any human being (when does a normal become a patient?) is premature before properly identifying the specific type. I would certainly recommend quantitative oculography for any person with 'wiggling eyes', so that it can be determined whether the oscillation is nystagmus or saccadic, what type it is and, only then, whether it is significant or not.

An excellent methodological paper by Barnes (8) discusses procedures for computer analysis of nystagmus that rely on the superior pattern recognition capabilities of the human operator. Such programs ensure proper criteria are used on

a case-by-case basis and avoid the pitfalls inherent in a fixed-criteria program which uses assumptions about average behavior (to achieve general applicability) that may introduce unacceptable errors in a specific case. A detailed description of a circuit that regulates the magnetic field strength of the two fields used in the search-coil technique of eye movement measurement appears in a paper by Optican et al (9). By also regulating the phase separation of the fields this circuit allows accurate registration of eye position, despite motion of the field coils (during vestibular testing) or motion of metal within or near the fields.

Abduction nystagmus

Abduction nystagmus is the dissociated nystagmus of the abducting eye seen in patients with internuclear ophthalmoplegia (10). The clinical picture presented by the patient with a complete internuclear ophthalmoplegia (INO) is that of an acquired jerk nystagmus of the abducting eye (with abducting fast phases), while the fellow eye remains motionless in primary position. If the INO is bilateral, abduction nystagmus will be present in both extremes of gaze, always in the abducting eye only. Abduction nystagmus has also been called 'ataxic' nystagmus of Harris. Careful recordings, using high bandwidth methods and simultaneous velocity tracings, have shown that the nystagmus slow phases are decreasing-velocity exponentials and that the fast phases of the abducting eye are always accompanied by hypometric saccades in the adducting eye. In fact, if the gaze angle is such that the adducting eye eventually reaches the target, both the abduction nystagmus and hypometric adduction saccades will cease. It is only in the full-blown INO, where the adducting eye does not adduct beyond midline, that abduction nystagmus persists. If the abducting saccadic pulses are truly the cause of this oscillation, then abduction 'nystagmus' should be classified as a saccadic oscillation.

Crane et al (11) studied the frequency of occurrence of the 4 characteristic eye movement abnormalities in 21 patients with INO. They concluded that the most sensitive pattern for detecting an INO was slowing of the adducting saccades combined with abduction nystagmus or with dysmetria of the abducting eye. They found that the incidence of this dissociated nystagmus, when gaze was directed 30° contralateral to the side of the medial longitudinal fasciculus lesion, was 91%; it fell to 38% when gaze was directed 15° eccentrically. These data are supportive of the hypothesis advanced above, but since no eye movement records were shown at these gaze angles, it could not be determined whether there were any corresponding hypometric saccades in the adducting eye during the abduction nystagmus.

Congenital nystagmus

Congenital nystagmus (CN) is present at birth or shortly thereafter. It may accompany afferent visual defects, but is not *caused* by defects in the visual system. Indeed, the oft-quoted association of pendular CN with a sensory defect and jerk CN with a primary motor defect is erroneous. The fact that in many cases one cannot distinguish by clinical observation alone the difference between the

several pendular waveforms of CN and the more numerous jerk waveforms further complicates such claims (which were made without eye movement recordings). Systematic ocular motility investigations have found no consistent association between waveform and the presence or absence of visual impairment, and both pendular and jerk waveforms have been documented in a single family with hereditary CN (12).

Although the visual deficit is not causal, it can contribute to the intensity of CN. CN is a high gain instability in the slow eye movement subsystem and fixation attempt (the effort to see) is its primary driving force; thus, CN is not a fixation nystagmus. Obviously, poor vision will increase fixation attempts, thereby causing nystagmus intensity to increase.

In a recent paper, Bagolini et al (13) tried to portray this disagreement about the causes of nystagmus as a disagreement between neurologists and ophthalmologists and cited several cases as evidence that sensory defects could cause nystagmus. My original objections (as a bioengineer) to the classical concepts of two different types of nystagmus differentiable by waveform were based on a control systems analysis of CN. We found that all CN represented a motor instability (whether pendular or jerk), and that many combinations of waveforms could be exhibited by the same person or several persons within the same family. Some people are born with normal eyes but too high a gain and therefore have CN at birth. In others, born with sensory defects, the gain is apparently higher than normal but not high enough to cause spontaneous oscillations. In these patients, the sensory defect can cause an increase in effort which results in higher gain and therefore in CN. Perhaps, in that sense, one might think that the sensory defect caused the CN, but if it were not for the fact that the ocular motor system was already compromised by a high gain, no CN would have resulted; this is obvious since many patients with the suspect sensory defects do not have CN at all. Thus, CN can exist with or without sensory defects, but in all cases it is the *same* CN caused by the *same* defect (a high gain instability).

CN can be diagnosed definitely by accurate eye movement recordings. The slow phases of jerk CN are increasing-velocity exponentials. Three pendular (pendular, asymmetric pendular, and pendular with foveating saccades), 8 jerk (jerk, jerk with extended foveation, pseudo-cycloid, pseudo-jerk, pseudo-pendular, pseudo-pendular with foveating saccades, triangular, and bidirectional jerk), and one combination of pendular and jerk (dual jerk) waveforms have been identified as CN waveforms (14). CN usually damps with convergence and, in many cases, a gaze angle can be found at which the intensity is minimal. Therapeutically, the nulling with convergence may be exploited by the use of vergence (base out) prisms in combination with -1.00 spheres added to the patient's refractive correction. The null angle may be exploited either by version prisms or, if the null angle is far removed from primary, by corrective surgery (15).

Our earlier work on smooth pursuit and CN (16) showed that the smooth pursuit response of a person with CN consisted of perfectly normal smooth pursuit superimposed on the existing CN waveform. It was also shown that the smooth pursuit system of a person with CN was able to track targets at higher velocities than normals, supporting the hypothesis that CN is due to a high gain instability in the slow eye movement subsystem. The superimposed CN was influenced by

the direction and velocity of the tracking movements in addition to eye position. Markedly asymmetrical responses were noted which were dependent upon the direction of tracking motion; this was due to a shift in the position of the CN null angle. The null shifted in a direction opposite to the smooth pursuit. Subsequent recordings of the pursuit of CN patients with all the various waveforms documented their ability to pursue both constant velocity and sinusoidally moving targets, and demonstrated that the shift in their null angle was a function of pursuit direction and velocity (17). Thus, many CN patients have a null angle which is static during fixation but dynamic during pursuit or optokinetic nystagmus (OKN). The gaze angle of the dynamic null is a function of pursuit direction and velocity and, therefore, can lie to either side of the static null angle. These observations were later confirmed by Halmagyi et al (18).

Larmande et al (19) illustrated how the smooth pursuit of a person with pendular CN consisted of the superposition of perfectly normal ramp tracking and the ongoing pendular waveform. This illustration of our original hypothesis (16) holds for all CN waveforms, not just pendular. In fact, most of the waveforms shown in their Figure 2 are pseudo-cycloid and jerk with extended foveation and therefore illustrate this point; the velocity trace in that Figure clearly shows the presence of saccades in every beat. These authors went on to try to explain OKN inversion in terms of this observation of smooth pursuit. As will be discussed below, OKN inversion merely reflects the reversal of ongoing CN as a result of a null shift. I would contend that the mere fact that the OKN stimulus induces a CN reversal (and therefore a null shift) is *prima facie* evidence that, despite the CN, the response to the less-than-optimal OKN stimulus is correct; the null shift opposite to the direction of the moving gratings is indicative of a pursuit movement, i.e. the slow phase of OKN, in the direction of the gratings.

Head-nodding has long been thought to compensate for CN. That would require the head oscillation to be equal in amplitude but opposite in phase to the eye oscillation and require the vestibulo-ocular reflex (VOR) gain to be suppressed to zero (20). Because of the complexities of CN waveforms we soon came to doubt that head-nodding could duplicate them. In 1978, Gresty et al (21) showed that head-nodding was not compensatory but actually a tremor associated with the CN; the head-nodding could easily be suppressed. During the head oscillation, the patient's normal vestibulo-ocular system causes compensatory eye movements which are superimposed on the CN waveform to preserve motionless foveation periods in the 'gaze' waveform (eye + head). In another class of patients, however, the head oscillation either is compensatory (by suppressing the VOR) or acts to suppress the eye oscillation and to utilize a normal VOR gain of unity (22). These patients have spasmus nutans which, although congenital, results in oscillations quite different from those of CN; also, the latter do not disappear with age. Thus, the head-nodding of CN patients is involuntary and not compensatory, whereas in spasmus nutans it may either be compensatory or be used to 'switch off' the eye oscillation.

LeLiever and Barber (23) presented the optokinetic responses of 15 patients with CN and/or manifest latent nystagmus (MLN). Although the bandwidth of their recording system was not given, the tracings shown were quite good considering they were obtained using electro-oculography. Identifiable CN waveforms are

evident and, in two of the patients, the diagnosis of CN was made from the eye movement record alone. Three of their patients had MLN (referred to in the paper as 'monocular fixation nystagmus') and 3 others had a combination of CN and MLN. As pointed out in this paper, it is very difficult to analyze the waveforms of patients who have both disorders. Since the CN and MLN contributions to the composite waveform can vary with time, the resulting slow phase can be either increasing in velocity, linear, or decreasing in velocity, at any given time. It is clear from these records that the so-called OKN inversion found in CN patients merely reflects a reversal of the patient's ongoing CN waveform.

Yee et al (24) concluded that the VOR is basically normal in patients with CN, whether or not they have associated ocular lesions. Volume 2 of this series contains a review of a paper on the OKN response of CN patients. The objections raised regarding methodology, data interpretation, and the arbitrary division of the patient population into two subgroups also apply, to some extent, to this paper and need not be repeated. However, the authors are on firmer ground using a simple computer algorithm to study vestibular nystagmus in CN patients than they were in studying OKN. If it is true, as stated, that many of the patients exhibited little or no CN when seated in the dark, the algorithm may function quite well if they still had no CN during rotation (this was not stated). For roughly 1/3 of their patient population, who demonstraded persistence of intense CN with eyes open in the dark, that algorithm will not work. It is not clear that the condition of the rotation in the dark is adequately duplicated by checking the CN while the patients are merely seated in the dark, since CN intensity is a function of several variables including anxiety and effort to see. The only way to determine whether the data analysis done by the computer algorithm properly represents the VOR of these patients is by looking at the raw eye movement data of each subject during rotation, and choosing only those which show clear saw-tooth vestibular nystagmus uncontaminated by their CN waveforms. The authors were aware of this problem and showed a case where CN was superimposed on the VOR. It is not surprising that the difference in VOR gain between the two arbitrarily chosen subgroups of the patient population was not significant, since ocular abnormalities could hardly be expected to have an affect on the VOR, which is measured in the dark. I take exception to the statement that both the saccadic and optokinetic systems of CN patients appear to have characteristic defects. No such defects have ever been shown to the satisfaction of this author and, based on more than a decade of quantitative evaluation of CN in our laboratory, these systems appear to be operating remarkably well when one considers the ongoing oscillation of the ocular motor system which must be taken into account by the saccadic subsystem of a CN patient. Since those with CN have no trouble localizing targets in their visual world, pursuing targets moving through their visual world, or stabilizing a target of interest on their retinas as they themselves are moving in the world, it strains credibility to state that these systems are defective and such claims call for careful scrutiny of methodology and data analysis. In fact, quite the opposite has been argued (17).

A very interesting paper by Yee et al (25) on the eye movement abnormalities

in rod monochromates has recently appeared. Some of these patients clearly had a low-amplitude pendular CN, but others appeared to have MLN, since their fast phases had prominent dynamic overshoots and the slow phases were decreasing-velocity exponentials. One patient (No. 3) did not appear to have any nystagmus at all; the record is a noisy wandering tracing containing one saccadic pulse. However, neither latent nystagmus nor manifest latent nystagmus was found in these patients by clinical examination or eye movement recordings. This creates quite a problem in interpretation: What did those patients, whose waveforms resemble MLN, really have? It was also stated that there was no evidence of strabismus. While small-angle strabismus can be missed on clinical examination, it is possible to detect it by eye movement recordings, although it may be difficult to do so with electro-oculography (EOG) (owing to its inherent drift). We recorded a similar patient many years ago; our impression at the time was that these were saccadic pulses, and sometimes double saccadic pulses, which took the eyes off the target and then returned them. Since we were never able to verify this with retinal cinematography, it is still an open question. These oscillations may be neither MLN nor CN but, rather, a saccadic instability. Some of the patients may have saccadic intrusions in combination with small-amplitude pendular CN. The computer algorithm employed to analyze the data from these patients probably worked quite well, given the low amplitude of the pendular oscillation and the sporadic nature of these saccadic intrusions. These patients exhibited both a slow build-up of the slow component of OKN and a directional asymmetry in OKN. Unlike CN patients, they all showed a well-developed OKN response. Also unlike CN patients, who can pursue normally, their pursuit gain was found to be decreased. Further study on rod monochromats aimed at identifying the type of instability present is warranted. Either retinal cinematography with a laser target or some other objective means to determine the position of the fovea relative to the target is required.

Kommerell and Mehdorn (26) advanced the hypothesis that both CN and latent nystagmus (LN) are due to inherent defects in the OKN and smooth pursuit systems. Along with putative basic defects is postulated the establishment of irregular 'nystagmus generators' (which are normally suppressed), due to the absence of an optokinetic control loop in these patients. We have learned from the study of feedback control theory and its application to neurophysiological systems that, along with the benefits of feedback, there comes the danger of oscillation. This recognition of the oscillatory behavior of feedback systems has resulted in our understanding of various neurophysiological tremors and oscillations, and negated the need to postulate hypothetical 'generators'. No such 'generators' have ever been found, save for the pacemaker cells in the cardiac system. Rather, it is well known that, in otherwise normal control systems, excessive negative feedback coupled with time delay or excessive gain in a positive feedback loop are responsible for oscillations. It is my opinion that, despite the references cited, no one has ever demonstrated a basic defect in the optokinetic system of a person with CN (nor would such a demonstration prove causality, given the necessity for a CN patient to suppress images which are constantly moving across his retina) and, furthermore, the smooth pursuit system of a person with CN is remarkably normal. These points have been discussed before both in this Chapter and in

Reference 16 and need not be repeated. Also, the lumping together of CN and LN reflects a basic misunderstanding of the significance of the shape of a slow phase. Increasing-velocity exponential runaways are due to an active instability, whereas decreasing-velocity drifts merely reflect the passive dynamics of the plant when faced with a position innervational mis-match. There are 3 specific points in this paper which require comment. The first is a statement that there was gross impairment of foveal pursuit which did not simply constitute a superposition of smooth pursuit and spontaneous nystagmus (reference is made to Fig. 4a). Quite the opposite is true. The pursuit shown in that Figure clearly reflects perfect superposition of a sinusoidal pursuit movement on a varying CN. One has merely to look at what would be the flat foveation periods in this waveform (jerk with extended foveation) to see that they have been modulated quite properly, so that their slopes reflect the velocity of the sinusoidal target they are tracking. In pursuit to the right they are sloped to the right and in pursuit to the left, where visible, they are sloped to the left. Of course, there are the expected changes in waveform during leftward pursuit due to the fact that the null has been shifted to the right, causing waveforms to undergo changes halfway through the leftward pursuit; in the rightward pursuit, the null has been shifted so far to the left that the whole field is that of jerk-right nystagmus. This is easily seen in slow tracking but is more difficult to see in the rapid tracking shown, since catch-up saccades are required at such high velocities. I think that the problem of interpretation here, and in other reported cases of 'abnormal pursuit', is due to the naive expectations of those doing the data analysis. The CN is *ongoing* and *will not disappear* simply because a person is pursuing a moving target. What must be learned is observation of the modulation of these waveforms to interpret properly the smooth pursuit. One must avoid the trap of mistaking the obligate saccades of a CN waveform for saccadic pursuit. When the CN is pendular, pursuit is accomplished by superimposing smooth pursuit on the CN waveform without saccades; when the waveform becomes a jerk CN, the ability to smoothly pursue is not suddenly lost. The person with CN foveates stationary targets and moving targets alike *only* at that point (or region) in his waveform after the refoveating fast phases. His visual system operates like a sampled-data system, taking pictures during the target-foveating portions of the waveform and ignoring all else. Thus, smooth pursuit can only be evaluated during the foveation periods of each waveform or during any segment in the null region if the nystagmus is completely absent. It is the researcher's unrealistic expectation of smooth, continuous tracking that has caused many to misinterpret perfectly normal smooth pursuit, as well as to declare that the optokinetic system of a CN patient has a basic deficit.

The second statement I take issue with is that the slow phases of LN can be exponentials of both decreasing and increasing velocities; Figure 5d is given as an example. In our laboratory, such a waveform would be diagnosed as belonging to a person with CN with a latent component, as first described by Kestenbaum (27). Such patients show variations in waveforms as well as CN amplitude with gaze angle, not seen in LN, and also show a null shift upon cover of either eye, the latter mimicking LN. However, since their waveforms are always those of CN and they may be perfectly binocular (without strabismus), they do not have LN. The third point regards apparent nasal-temporal asymmetries in pursuit

or optokinetic response of patients with LN. These asymmetries reflect nothing more than the ongoing LN superimposed upon the response which is being measured. They do not indicate a basic asymmetry in the OKN control system. Despite my disagreement with the theoretical hypotheses made in this paper, the data presented are good and reveal many points about CN and LN if properly interpreted. Specifically well done is the section dealing with Van Vliet's experiment in patients with LN. Here, the authors clearly show that it is the viewing eye which determines the direction of the LN and not the eye which is thought to be viewing by the patient. The authors do recognize the need to use 'a recording system which allows accurate monitoring of the position of the fovea versus the position of the target'. We have long recognized that need and have been using such a system for the last decade; it is precisely because we do know the eye position relative to the target that we were able to understand many of the complexities of CN and LN and arrive at the hypotheses that we have presented during this time.

Yee et al (28) reported on the successful use of baclofen in the treatment of CN. By plotting the nystagmus intensity versus gaze angle pre- and post-treatment, they showed objective data documenting the benefits of this therapy. Significantly, the patients who underwent this therapy reported that 'less effort was required for clear vision'. Part of the beneficial effects we have long ascribed to prisms and surgery has been the reduction in an overall fixation attempt or effort to see. Here we see a drug therapy which resulted in less effort and, simultaneously, with lower nystagmus intensity. For the reasons discussed above, I would disagree that the drug improved the smooth pursuit of the patient; what it did was to reduce the spontaneous nystagmus superimposed on already good smooth pursuit. There is a discussion and presentation of inverted OKN in this paper, but the particular patient chosen was not optimal; he may have had the nystagmus blockage syndrome since he was able to damp his nystagmus markedly by a purposive esotropia. It appears from these tracings, which are highly filtered, that the esotropia converted an ongoing CN to a MLN. It is very difficult to interpret the optokinetic response of such a patient without seeing the whole record to know the extent to which he mixed MLN waveforms with CN waveforms. Again, given the nature of the stimulus and the constant high velocity motion of the retina, this should not be interpreted as a basic defect in the OKN system. Until we devise a way to truly test the effects of slowly moving gratings on an oscillatory retina, very little can be said about the basic OKN mechanism of a CN patient. For these reasons, we do not routinely test the optokinetic responses of CN patients; CN is identifiable by waveform.

We have always assumed that the variation of CN with gaze angle was only a function of the angle of the eye with respect to the head. Thus, there would be no difference in the CN waveform if a patient was looking at a target directly in front of him with a 15° head turn to the right, or looking at a target 15° to his left with his head straight. This is reflected in the methods we use for testing, i.e. the head is held straight and the person is directed to look at targets at various gaze angles, and has been supported by the positive results of the use of prisms to shift the target relative to the person, and of surgery, which rotates the eyes within the head. Recently, Lomas et al (29) examined the possibi-

lity that actual head turn may have some effect on the CN amplitude and waveform. They studied both patients with CN and normal eyes and albinos with CN. They found that, in fact, the variation of CN with gaze angle was unaffected by head position. In an accompanying paper, Abadi et al (30) examined the OKN responses of patients with idiopathic CN plus albinos with horizontal CN and those with rotatory CN. They verified the effects of null shift by noting that if the stimulus field moved from right to left, the CN recorded was that habitually found on looking to the left even though the eyes were directed towards primary position; if it moved from left to right, the right-gaze CN was apparent. They noted that higher stimulus velocities were more likely to initiate this response, i.e. the null shifts further with higher velocity, and that the nystagmus was not true reverse-OKN but consisted of CN waveforms. Binocular responses showed the same pattern. The binocular responses of the albino observers were similar to those of the idiopaths. Their monocular responses, regardless of the stimulus direction, tended to show persistence of the primary position CN, i.e. there was no null shift. Neither group showed any directional asymmetries for monocular viewing. The albino with rotatory CN exhibited a normal OKN waveform for both binocular and monocular responses; the monocular response was also asymmetrical. They concluded that CN inversion with OKN stimulus is pathognomonic of CN only when the stimulus moves in the same meridian as the spontaneous CN. This was verified by subjecting a patient with vertical CN to a horizontal OKN stimulus; there was no inversion or asymmetry. Thus, OKN asymmetry is related to foveal function (this is supported by its presence in rod monochromats (25)) and unrelated to CN as cause or effect.

As a result of work presented by Optican et al (31) we now know that the smooth pursuit-induced null shift in CN is instantaneous and simultaneous with the onset of pursuit. They ingeniously prensented a step-ramp stimulus to a CN patient who was viewing the target at a gaze angle to the left of his null (therefore, he had jerk-left CN), opened the feedback loop with the onset of the stimulus and closed it again 400 ms later. What they observed was a reversal of the patient's CN at a point 130 ms after the onset of the stimulus. Thus, the CN reversal was coincidental with the beginning of smooth pursuit, indicating that the null had instantaneously shifted far to the left and the patient, whose gaze angle had not yet changed, was now in a jerk-right field. Unfortunately, by assuming that the null was solely a function of gaze angle, these authors misinterpreted the CN reversal as reversed pursuit and stated that pursuit was abnormal in their CN patients. I have already commented on the reasons for such a misinterpretation. This paper also reaffirmed, albeit in a different way, the well-known fact that the presence of CN does not depend on retinal slip; fixation attempt is responsible for the genesis of CN in the dark or light (12).

A recent paper on the relationship between achromatopsia and CN (32) contains some errors which already have been commented on in a Letter to the Editor (33). The paper does make the clinical point that achromatopsia should be tested for in CN patients and describes a method of doing so.

A follow-up to our original paper on CN surgery has shown the long-term stability of the resulting changes in location, breadth, and depth of the null zone (34). Also discussed is the importance of waveforms and their insensitivity to

surgery. Dorn and Celic (35) presented the results of an electronystagmographic evaluation of the results of CN surgery. Despite what appear to be low bandwidth, bitemporal EOG recordings with AC coupled electronics, the figures presented do show the beneficial effects of the surgery in shifting the null and reducing the intensity of the nystagmus; also shown are the beneficial effects of using prisms. Estes et al (36) reported the successful surgical treatment for rotary CN associated with a head turn. The importance of this paper lies in the observation that a horizontal head turn can be corrected surgically, and at the same time result in minimal rotary CN. The paper itself contains many misstatements, including the well-known but erroneous 'sensory defect-motor defect' classification equated to pendular and jerk waveforms, respectively. If the reader can ignore discussion of the above, he will come away with the important observation. Also stated in this paper is that surgery is a good *long-term* method for treating CN, correctly contradicting another ophthalmological myth, i.e. that the head turn will return in several months. Kaufmann and Kolling (37) discussed the advantages of doing the Cüppers operation in those patients with CN who have good binocular function and a decrement of CN intensity during near vision. They recommend this operation whether or not the patient has an abnormal head position, i.e. an eccentric null angle, and claim that the results are better than the Kestenbaum/Anderson operation. This is consistent with our observations that the use of base-out prisms in such patients often removes the head turn and results in better vision, and can be used instead of surgery. Thus, if a strong convergence effect is present in a CN patient, either prisms or surgery can be used to take advantage of this effect instead of trying to shift the null either surgically or with the use of version prisms.

The subject of the effects of convergence on CN brings us to a study on the nystagmus blockage syndrome (NBS) (38). Using quantitative oculography we documented CN waveforms when an NBS patient was viewing at a distance which then diminished and abruptly changed to MLN when one eye became esotropic. Such a peculiar transition from CN to MLN had not been previously described and reflects two entirely different mechanisms for their generation. This is in contrast to the case reported by Kommerell (39), and to another case which we have since recorded, in which the CN damps considerably when one eye becomes esotropic but remains a CN waveform. Thus, there are two different types of the NBS, differentiable only by accurate recording. It should be pointed out that when clinical inspection is relied upon, this syndrome is overdiagnosed in many cases of MLN which varies in accordance with Alexander's law and is associated with esotropia.

Another treatment for CN which has received attention in the last few years is auditory biofeedback. Ciuffreda et al (40) reported on their experience with this method. The keys to whether auditory biofeedback can become a viable tool in the treatment of CN are as follows: ease of training, significant reduction in the CN intensity resulting in higher acuity, and ability to employ the techniques learned outside the laboratory under conditions of stress. All of these points are addressed in this paper. Specifically, the method is apparently readily learned by the patients, since within 1 hour of training, all patients were able to reduce their nystagmus. Despite significant reduction of the nystagmus intensity in all

5 patients, the visual acuity increase did not appear to be large. However, when one considers that one of the 3 CN patients and the patient with acquired nystagmus both had binocular acuity of 20/20 and that the LN patient had no nystagmus under the binocular viewing conditions, it is not surprising that there was no great improvement in acuity in these cases. The authors do point out the significance of even a one-line improvement on the Snellen chart. For CN patients, if that line enables them to obtain a driver's license, it is a major improvement in the quality of their lives. While biofeedback would not benefit a patient with pure LN very much unless he had a specific need to use monocular vision, the fact that most patients have MLN makes the demonstration that biofeedback can reduce the amplitude of LN an important result. Also significant is the finding that someone with acquired nystagmus can take advantage of this technique. Based on their discussion of these patients, it also seems that they were able to use the techniques learned in the laboratory in everyday life when not able to benefit from auditory biofeedback. Thus, biofeedback emerges as another tool which can be used to treat both congenital and other forms of nystagmus.

Coupland and Kirkham (41) presented an interesting method to obtain the electroretinograph (ERG) from a patient with ocular nystagmus by using infraorbital skin electrodes. By simultaneously measuring the EOG from the occluded eye and the ERG plus the EOG from the non-occluded eye, the former signal could then be subtracted from the latter to obtain a purer ERG. Of course, this method rests on the assumption that the nystagmus in the two eyes is equal in amplitude, direction and velocity. This was apparently verified for the patients studied, but must be verified for each patient since this is not always the case in congenital nystagmus, i.e. the amplitudes of the two eyes are not always equal although the direction and frequency are. The authors point out that this technique is useful in cases where there are abnormal eye movements which would normally interfere with the accurate recording of the ERG.

Downbeat nystagmus

Downbeat is a vertical jerk nystagmus present in primary position that was originally described with linear upward slow phases and fast phases beating in the downward direction. It is highly suggestive of a disorder of the cranio-cervical junction such as Arnold-Chiari malformations. Contrary to Alexander's law, it is not maximum in the extreme of downward gaze, but is usually of maximal intensity when the eyes are deviated laterally and slightly below the horizontal. It has also been described in patients with presumed parenchymal cerebellar disease (42). A defect in downward pursuit was suggested as the cause of this form of 'pursuit-defect' nystagmus (43). However, the whole concept of 'pursuit-defect' nystagmus has been questioned (44) and Baloh and Spooner (45) have argued that downbeat nystagmus is a type of central vestibular nystagmus.

The first indication that the slow phase waveform of downbeat nystagmus may not always be linear appeared in a paper by Zee et al (46) in which they showed recordings of a patient whose downbeat nystagmus had increasing-velocity upward slow phases. This paper was shortly followed by that of Pedersen et al (47) which showed a case of intermittent downbeat nystagmus with increasing-velocity

upward slow phases. We have recently completed a study documenting variable waveforms of downbeat nystagmus and equating them to short-term gain changes (48). In a patient with downbeat nystagmus consequent to ankylosing spondylitis we found both increasing- and decreasing-velocity exponential slow phases as well as linear slow phases. We also found alternation between these waveforms on a beat-to-beat or even intrabeat basis. A computer model was developed in an attempt to explain these developments. In another study on a patient with downbeat nystagmus due to nutritional deficiency (49) we recorded downbeat nystagmus with pseudocycloid waveforms; this waveform had only been previously described in congenital nystagmus in the horizontal direction. The slow phase of a pseudocycloid waveform is an increasing-velocity exponential, but the fast phase does not fully refoveate the target since the braking saccade is too small. Target refoveation is accomplished by a slow movement following the initial saccade of the fast phase. Thus, the fast phase would appear to be made up of a braking saccade produced by a pulse-step mismatch, where the pulse was too small but the step was large enough to allow the eye to foveate the target with a glissadic movement. Our studies of this patient's eye movements showed a decrease in the downbeat nystagmus with convergence that we utilized therapeutically by adding base-out prisms to each of her spectacle lenses. This resulted in an improvement in her visual acuity.

Drug-induced nystagmus

A horizontal or horizontal-rotary jerk nystagmus which is gaze-evoked may be induced by the administration of barbiturates (barbiturate nystagmus), tranquilizers, phenothiazine, and anticonvulsant drugs. Vertical nystagmus is often present on upward gaze but only rarely on downward gaze. The nystagmus may be quite dissociated in the two eyes despite the lack of structural disease. Severe intoxication may result in a horizontal, pendular nystagmus at primary position. Careful history taking and drug-screening blood studies are essential in evaluating patients with nystagmus.

Two recent papers reported the incidence of drug-induced downbeat nystagmus. Berger and Kovacs (50) observed downbeat nystagmus secondary to phenytoin intoxication. Wheeler et al (51) observed drug-induced downbeat nystagmus secondary to carbamazepine. The downbeat nystagmus was observed whether carbamazepine was given alone or in combination with phenytoin and phenobarbital. The patient reported by Berger and Kovacs received only phenytoin and the downbeat nystagmus disappeared when the phenytoin levels were reduced to the therapeutic range. Jay et al (52) observed primary-position upbeat nystagmus due to organophosphate poisoning. Treatment of the patient with intravenous atropine resulted in a resolution of the nystagmus. Unfortunately, there are no eye movement recordings in any of the 3 preceding papers. Thus, the exact nature of the oscillation (nystagmus or saccadic) has not been confirmed nor has the slow-phase waveform been described, assuming it was nystagmus. These phenomena must be studied quantitatively before speculating on the mechanisms responsible for their generation. Odkvist et al (53) found that industrial hydrocarbon solvents can produce a positional nystagmus and affect both optokinetic and vestibular

responses in rabbits. Human volunteers, however, did not get any positional or spontaneous nystagmus at the blood concentrations used. Rabbits developed ageotropic nystagmus and cats developed vertical downbeat nystagmus when in a prone position. Since with premedication with the γ-aminobutyric acid (GABA)-agonist, baclofen, it was not possible to elicit positional nystagmus in rabbits, they concluded that the solvents acted by blocking GABA.

Flash-induced nystagmus

Flash(flicker)-induced nystagmus is a jerk nystagmus induced by intermittent photic stimulation of one eye. The direction of flash-induced nystagmus is always towards the stimulated eye; for this reason, it has been suggested that flash-induced nystagmus is related to latent nystagmus (54). Flash-induced nystagmus differs from optokinetic nystagmus in that it is abolished after bilateral labyrinthectomy and is affected by head and body position (55).

Van Dalen (56) equated the mechanism of flash-induced nystagmus to that of latent nystagmus. Since the tracings were obtained using AC-coupled, low-bandwidth electro-oculography with what were probably bitemporal electrodes, it is impossible to compare accurately the waveforms of flash-induced nystagmus to those of latent and manifest latent nystagmus; however, the waveforms do look similar and, if they are in fact the same, the comparison is a valid one. Further studies of flash-induced nystagmus using high-bandwidth DC-coupled electronics and simultaneous recording from each eye are necessary to document the exact waveform of the nystagmus, as well as the position of each eye in the orbit. The fact that flash-induced nystagmus was only elicited during monocular stroboscopic stimulation is the basis for the similarity to latent nystagmus, which requires monocular fixation. Latent nystagmus (LN) and manifest latent nystagmus (MLN) are absent during binocular fixation, but MLN is present during binocular viewing if fixation is being accomplished monocularly. The term 'binocular viewing', as we use it, implies that both eyes are open but does not imply binocular fixation. In the paper, however, binocular viewing appears to be equated to binocular fixation. This ambiguity in terms makes it difficult to interpret the statement that in LN there is 'hardly any nystagmus' during binocular viewing; there should be *no* nystagmus during binocular fixation (true LN), and if there is nystagmus during binocular viewing (MLN), then the patient is fixating monocularly. The intriguing relationship between flash-induced nystagmus and LN should be studied further using quantitative ocular motility techniques.

Latent/manifest latent nystagmus

Latent nystagmus (LN) and manifest latent nystagmus (MLN) are nystagmus types elicited by monocular fixation (57). The nystagmus is jerk with the fast phase towards the fixating eye. Although LN/MLN is usually a congenital form of nystagmus, the slow phase is a decreasing-velocity exponential. Thus, it is not true congenital jerk nystagmus which has an increasing-velocity exponential slow phase. MLN occurs in patients with amblyopia or strabismus who, although viewing

with both eyes, are fixating monocularly. The direction of MLN in patients with alternating fixation is always in the direction of the fixating eye. Such patients are usually misdiagnosed as having congenital nystagmus (CN), since the nystagmus is present with both eyes open. Accurate eye-movement recordings are the only way to document the nystagmus and diagnose it properly. Unfortunately, most physicians and researchers are unaware of the important clinical and functional differences between MLN and CN and cannot distinguish between these two separate congenital forms of nystagmus.

Although MLN does not have a null angle (this is shown in Fig. 9 of Ref. 57), the variation of MLN with gaze angle in accordance with Alexander's law may result in a head turn. Usually the head turn is such that the fixating eye is in adduction. If the patient is an alternate fixer, he may adopt a right head-turn when fixating with the right eye and a left head-turn when fixating with the left eye. It becomes very important, therefore, to distinguish MLN from CN before any consideration of surgical intervention is made. Surgery for CN will depend on the location of a true null, whereas surgery for MLN should be performed only if the patient consistently fixates with one eye and accompanies this fixation with a head turn. Alternate fixers who adopt alternate head-turns cannot be helped by surgical rotation. As pointed out in this paper, the situation is complicated by the fact that some patients have neither a pure CN nor a pure MLN; various combinations of the two exist and the only way to diagnose the condition accurately is by means of ocular motility recording and waveform analysis.

In the early 1970s our studies of foveation and congenital forms of nystagmus, using laser-target retinal cinematography, revealed that, in both CN and LN the slow phases brought the fovea off target and the fast phases returned it to the target (for some CN waveforms, towards the target). This relation of LN waveform to foveation was discussed by Daroff et al (20), shown in Figure 10 of Dell'Osso et al (57) and has been observed by Lang (58). Armed with this knowledge, we were able to align exactly the tracings for each fixating eye (the other eye being behind cover) and, when the cover was removed, could detect, and had a record of, even the smallest tropias during binocular viewing, i.e. both eyes are open. Thus, in addition to a DC-coupled, high-bandwidth recording system with low drift, low noise and high sensitivity, monocular calibration is required to preserve accurate eye-position information for each eye. It is only when one can be sure that a specific eye is fixating the primary-position target that the position tracing of that eye can be properly aligned to the zero line on the recording paper. This is true whether there is an ongoing nystagmus in either or both eyes. When each eye is properly calibrated monocularly, cover can be removed in the presence or absence of small tropias easily determined or measured objectively. Similarly, when either eye is placed under cover, small phorias can be measured since both eyes are being simultaneously recorded whether or not they see the target. This methodology provides an objective way to measure both the magnitude of tropias and phorias in patients with nystagmus and to record their variation with time; the latter is impossible using subjective clinical office procedures which are difficult and often yield ambiguous results. This calibration procedure (employed in previous studies of both CN and LN/MLN) was pivotal in a recent study which allowed us to observe the relation-

ship between strabismus and LN/MLN (59). Whenever there was an ongoing LN or MLN, the non-fixating eye was in a phoric or tropic position, respectively. We concluded that strabismus is a necessary condition for the presence of LN or MLN, i.e. all patients with LN or MLN have strabismus. It is obviously not a sufficient condition since strabismus does exist in the absence of nystagmus.

Harcourt et al (60), in a paper on dissociated vertical divergence (DVD), mentioned the association between this condition and nystagmus, 'often manifest'. In an earlier paper, Mein and Johnson (61) reported 100 patients with DVD, emphasizing that nystagmus was present in every case; all their patients lacked worthwhile binocular function. In this follow-up paper on the same 100 patients it is stated that 22 had manifest nystagmus when first examined; in others the nystagmus was described as unilateral which became more latent in character. Since there are no recordings of these patients, it is impossible to tell whether we are dealing with CN, CN with a latent component, LN or MLN. Similarly a paper by Clarke and Noel (62) on DVD and LN mentions 2 patients in which the LN was first noticed at the ages of 25 and 39 months, respectively. Without recordings neither the type of nystagmus nor the age of onset can be accurately determined; what may not be noticed clinically can be recorded with accurate techniques.

Hoyt (63) studied 32 infants with congenital esotropia. Twenty-four of his patients did not have nystagmus and the remaining 8 were said to have the nystagmus blockage (compensation) syndrome (NBS). The paper contains no eye-movement recordings and, without them, it is impossible to differentiate CN from MLN, let alone make the diagnosis of NBS. Based on our experience in recording over 300 CN and MLN patients (including 2 with NBS), we suspect that Hoyt's patients all had MLN, which varied in accordance with Alexander's law, and did not have NBS; this is in agreement with others who caution that NBS should not be confused with infantile esotropia accompanied by MLN. There is an unfortunate use of the term 'abduction nystagmus' in describing these patients. This term, used to describe the Alexander's law variation of a conjugate nystagmus, should be reserved for the dissociated nystagmus of internuclear ophthalmoplegia where it was originally applied (see section on Abduction nystagmus, p. 161).

Three papers have recently appeared on assessing monocular visual acuity in LN. Evans et al (64) described a method using a duochrome slide and the green filter of the Worth red-green glasses. This method may be as good as, or in some cases better than, other commonly used methods (opaque-occluder, + 5.00 lens or vectograph). The object in these tests is to obtain the maximum acuity for each eye monocularly by creating conditions which diminish any LN or CN with a large latent component. An interesting discussion of this paper by Ronald Price is appended. He points out that none of the methods gives monocular acuities which approximate the binocular situation, but that the + 5.00 lens and this green filter test do give visual acuities which are statistically different from the occluder test. Also mentioned is the need for a larger sample so as to give significance to these differences if they are to be used to detect amblyopia. Haase and Schulz (65) described another method to test monocular acuity in patients with LN. They made use of a 20×30 cm screen containing a viewing hole which

was held up in front of the patient. Again the object was to minimize the nystagmus and obtain the maximal acuity monocularly. A final paper on the subject by Dorman (66) presented a case report of a patient with LN. The vectographic method with polaroid filters was employed to obtain monocular acuity. Unfortunately, both the description of LN as being 'induced in the fixating eye when the other eye is covered' and the observation that 'the slow phase is usually toward the side of the covered eye' are incorrect. LN is a conjugate nystagmus of *both* eyes and the slow phase is *always* towards the covered eye.

Lid nystagmus

Lid nystagmus, originally described by Pick (67), is a rhythmic, upward jerking of the upper eyelids, which usually represents coordinated movements of the lids and eyes during vertical ocular nystagmus. There are 3 types of pathological lid nystagmus (68). The first type coexists synchronously with vertical ocular nystagmus, but the amplitude of the lid movements exceeds that of the eyes; the second type is evoked by lateral gaze and is characterized by rapid twitches of the lids in synchrony with the fast phases of the horizontal ocular movements; the third variety is provoked by ocular convergence. The first type has no localizing value, the second type may be a sign of lateral medullary syndrome, and the third type has been associated with a large area demyelination in the rostral medulla extending laterally across the medial lemnisci, immediately dorsal to the upper border of the inferior olives.

Safran et al (69) discussed 2 patients whose lid nystagmus was induced by ocular convergence. In both, there was cerebellar involvement and the convergence-evoked lid nystagmus disappeared after treatment (corticosteroids in one and surgery in the other). An electro-oculography record showed lid nystagmus with a frequency of 2–4 Hz that appeared during convergence. The lid nystagmus consisted of slow downward deflections and rapid upward deflections. Although the EOG was AC-coupled, its 6-second time constant was long enough to prevent significant distortion of the nystagmus waveform. Also, since each eye was recorded individually, the record showed the nystagmus to be conjugate; this is probably the best record of lid nystagmus in existence. The authors present 2 hypotheses for the generation of lid nystagmus. In the first, they draw analogy to gaze-paretic nystagmus (found in cerebellar lesions), which is due to inability of the ocular motor system to maintain eccentric gaze position or to correct an innate drift. In this case the lid nystagmus would be caused by the inability to maintain the physiologic eyelid retraction normally evoked by convergence. In the second hypothesis an analogy is drawn to convergence-retraction 'nystagmus', an oscillation that is saccadically initiated. Since the authors were unable to determine whether lid nystagmus was regularly initiated by an upward jerk or a downward drift of the upper eyelid, it was not immediately obvious whether the lid nystagmus was truly a nystagmus or more analogous to a saccadic oscillation. However, given the facts that normal convergence evokes a widening of the palpebral fissure, and that these patients did not initiate their lid nystagmus by upward saccades nor was there rhythmic eyeball retraction or convergence, the hypothesis evoking gaze-paretic nystagmus seems to this author to be the better of the two.

I would conclude, based on their evidence, that lid nystagmus is truly a nystagmus elicited by slow downward drifts of the lid, corrected by upward flicks of the lid and caused by involvement of the cerebellar system.

Optokinetic nystagmus

Optokinetic nystagmus (OKN) is a form of induced jerk nystagmus which is extremely valuable diagnostically. The nystagmus is induced by presenting to the subject a visual pattern which moves with constant velocity in a given direction. The induced eye movements consist of constant-velocity (linear), conjugate eye movements in the direction of the moving stimulus interspaced with fast phases in the opposite direction. OKN has been called kinetic, optic, optomotor, panoramic, railway and train nystagmus. Stationary visual patterns illuminated by intermittent flashes can also induce OKN; this is called sigma-OKN (σ-OKN). OKN testing can be used to document the existence of vision in infants or patients with fictitious visual loss, to localize cerebral hemispheric lesions, to induce convergence-retraction 'nystagmus', to demonstrate the adduction insufficiency in internuclear ophthalmoparesis, to diagnose ocular motor nerve misdirection, to diagnose ocular myasthenia gravis (by injecting anticholinesterase during the OKN test and noting the velocity of the fast phases) and to diagnose congenital nystagmus (by getting inversion).

Despite the clinical importance of OKN testing, the literature on the subject is as confusing as it is voluminous. There is disagreement among those currently doing OKN research about both the nature of an adequate OKN stimulus and the characteristics of a true OKN response. According to one school of thought, OKN is divided into two types: Stier and Schau nystagmus. This is based on the work of Ter Braak (70), who equated the Stier (field) OKN with subcortical mechanisms, while the Schau (object) OKN was related to cortical mechanisms. In man, this is equivalent to full-field versus central-field (foveal) OKN. Clinically, it is the foveal OKN which is stimulated by the familiar OKN tape. The work of Dichgans (71) seems to support the hypothesis that one can simulate a full-field stimulus with a 90° horizontal strip. At the other end of the spectrum, Robinson (72) is of the opinion that true OKN must induce circular vection and must be followed by optokinetic after-nystagmus (OKAN). Any stimulus which does not produce OKAN and circular vection is, therefore, inducing a 'pseudo-OKN' which is probably mediated by the pursuit mechanism in man. Because one cannot dissociate the function of pursuit in the full-field stimulus condition, Robinson proposed that the OKN mechanism can be isolated only by studying OKAN. The picture is further complicated by the interrelation between the vestibular system and the OKN system (73). A paper by Muratore and Zee (74) on pursuit after-nystagmus has raised serious questions about Robinson's definition of OKN. They found that simple pursuit induced an after-nystagmus. Thus, we are faced with the fact that both full-field stimulation and pursuit of a simple foveal target can induce an after-nystagmus, and it may be impossible to separate true OKN from pursuit OKN if, indeed, they result from different mechanisms. While it has been presumed that pursuit is a foveal reflex, evidence has been presented (75) that pursuit need not be foveal. It is within the context of these conflicting

views on the nature of an adequate stimulus for OKN that one must read the literature on this subject. When all the evidence is in, we may find that, despite differing functions and phylogenetic origin, both the optokinetic and the pursuit response are mediated by the same neurophysiological efferent mechanisms, and differ only in afferent magnitudes. That is, the magnitude of the following response would be related to the amount of retinal area stimulated and the percentage of that area that is in the direction of motion. Similarly, the ever-present interaction with the vestibular system could be proportional to the following response elicited by the particular stimulus presented. Thus, a small stimulus in the periphery would elicit a weaker response than a stimulus whose image was a visual strip across the retina (including the fovea), where the long direction of the strip corresponds to image motion. As the stimulus becomes more compelling and the resultant following response harder to suppress, one might move from the 'pursuit domain' to the 'optokinetic domain' without necessarily changing the mechanism responsible for the respective responses. Of course, the retinal sensitivity map will vary from species to species depending upon the morphology of the individual retinas.

A very good review of the role of OKN in the ophthalmological examination of infants was written by Hoyt et al (76). In addition to discussing several techniques to detect visual dysfunction, these authors make it clear that the terms 'sensory' and 'motor', when associated with congenital nystagmus, are not pathogenic terms. Naegele and Held (77) reported, in their study of postnatal development of monocular OKN in infants, a direction-dependent slow-phase asymmetry until 5 months after birth. The roles of central and peripheral retinas in OKN asymmetries were studied by Van Die and Collewijn (78), who concluded that the central 10° of the retina was the most powerful in eliciting OKN, followed by the parafoveal and peripheral retina. They also found that OKN gain was asymmetrically higher for: the right eye; temporal to nasal rotation; foveopetal motion during hemifield stimulation; and foveofugal motion during parafoveal stimulation. Malach et al (79) found the OKN asymmetry present in young kittens (nasalward stimulus movement greater than temporalward) not significantly different between normal, monocularly deprived and strabismic cats. They concluded that OKN asymmetry is not related to cortical binocularity. In strobe-reared cats, Kennedy et al (80) found OKN asymmetry more pronounced than in normal animals. Vestibulo-ocular reflex interaction with OKN was absent in the strobe-reared cats. Kawano and Sasaki (81) found what they called 'OKN neurons' in Area 7 of the cortex. These neurons responded only to OKN stimulation and did not respond to smooth pursuit or vestibular stimulation. OKN neurons were hypothesized to provide information on movement of visual surroundings whether or not they were being pursued. In an attempt to understand the contribution of efferent vestibular inputs to vestibular-OKN interaction, Büttner and Waespe (82) found that vestibular nerve activity was not influenced as a result of OKN patterns or additional visual stimuli. This activity was determined solely by head acceleration and, therefore, OKN effects are introduced at the vestibular nuclei. Calhoun et al (83) studied the effects of position change (otolith interaction) on both OKN and OKAN. No changes were found in either horizontal or vertical OKN but tilt did produce asymmetry in vertical OKAN. The nature of the interaction

between vestibular nystagmus and OKN was studied by Holm-Jensen (84). With slow target speed, both systems contributed to the resulting nystagmus as independent superimposition of the two types. Since interaction has been found at higher target speeds, the question of the existence of a common integrator is discussed in this paper. Stereopsis in OKN was investigated in normal subjects and in subjects with impaired stereovision (85). Monocular OKN was found to be directionally asymmetric in all stereoblind subjects. The authors concluded that there was a connection between binocularity and symmetry or asymmetry of monocular OKN. Mehdorn (86) studied the nasal-temporal asymmetry of OKN after a bilateral occipital infarction in man. He showed that destruction of a great part of the visual cortex and of corticofugal pathways can uncover the subcortical OKN system which contains the asymmetry. He concluded that, in man, even the subcortical OKN system largely depends on cortical input. A very good paper cataloging OKN deficits with clinical abnormalities was written by Baloh et al (87). It discussed deficits in fast phase as well as both portions of the OKN system. Also included in this paper is a model containing the two components of OKN (cortical and subcortical), as well as studies of pursuit-OKN interaction which would be predicted by this model. They conclude that, as a good first approximation, linear interaction between two parallel pursuit systems in man is a reasonable model. While on the subject of models, several papers have recently appeared, each treating the optokinetic system in a slightly different way in an attempt to model several of its facets. Hoffmann (88) presented a model which relates the neural activity differences in the left and right nuclei of the optic tract with the gain of OKN in the cat. Lisberger et al (89) and Buizza and Schmid (90) presented excellent model studies of the OKN system. The former was aimed at the sensitivity of the OKN system to long-term adaptive changes in the vestibulo-ocular reflex, while the latter elaborated on a previous model of combined vestibular and optokinetic stimulations. A thorough discussion of the strong points and limitations of each of these complex models is beyond the scope of this chapter. They are both recommended reading for those interested in modeling various parts of the ocular motor control system. An interesting study by Böhmer and Allum (91), which also contains a model, discussed OKN responses under quasi-open and closed-loop conditions. They suggested that open-loop testing of the dynamics of the direct OKN pathway would be a useful way to study the effects of damage to and recovery from lesions in this pathway alone, i.e. eliminating the storage mechanism generating slow-phase velocity via the indirect pathway.

Schor and Narayan (92) reported that OKN responded optimally to coarse gratings whose upper spatial frequency limits varied inversely with test field size. They also identified an upper temporal frequency limit of 24 Hz, which was related to the critical fusion frequency for detecting drifting gratings, and found that smooth pursuit OKN replaced involuntary OKN for low-velocity stimuli. Holm-Jensen (93) studied the influence of target width and speed on OKN in non-symmetrical gratings; both had a reciprocally modifying effect on OKN regularity. While the width of the targets did not modify slow-phase velocity, it was positively correlated with OKN frequency. Hulk and Rempt (94) found that partial stimulation by vertically moving patterns in the periphery of the temporal field of vision on one eye can produce sensations of lift and apparent tilting of vertical

objects in the line of sight. This sensation of linear vection is greatest with slow angular velocities in the far periphery. These observations are discussed in relation to disorientation in pilots and also to movement of text on terminals and monitor screens.

Several recent papers have appeared on the subject of sigma-OKN and sigma-movement; the latter is the apparent movement seen when a stationary periodic visual pattern of period (P) is illuminated stroboscopically at a flash frequency (f) during a smooth pursuit eye movement of angular velocity $\dot{\theta} = P \times f$. Collewijn et al (95) found that the higher the general level of attention and the better the 'attention fovea' coincided with the retinal fovea, the higher the velocity gain of sigma-movements. When the attention fovea was separated from the retinal fovea, the gain decreased to a value less than 1. The extent to which the slow phases of OKN depend on external stimulus parameters, the part of the retina stimulated, the level of general and visual attention and the state of spatially selected visual attention is discussed in detail including several illustrations from commonly occurring 'real-life' situations. Adler and Grüsser (96) found sigma-OKN as a result of three-dimensional periodic stripe patterns generated by monocular stimuli. Since sigma-movement is caused by the interaction of efference copy signals and afferent visual signals, they concluded that the neuronal mechanisms for this interaction are located at or beyond the level of binocular fusion and stereopsis. In the first study of sigma-OKN in neurological patients, Buettner et al (97) found perception of sigma-movement and sigma-OKN in patients with brainstem lesions but not in patients with cerebellar lesions. They were able to demonstrate perfect sigma-pursuit in patients whose normal smooth pursuit was severely disturbed. They concluded that the interaction between efference copy and afferent visual signals takes place outside the brainstem.

The usefullness of OKN testing was reported on by Abel and Barber (98). They compared normal patients with chronic unilateral labyrinthectomy, unilateral Meniere's disease, focal brainstem lesions, brainstem-cerebellar syndromes, and focal unilateral supratentorial lesions. They found the OKN slow-phase velocity lower in patients with brainstem disease. Patients with chronic peripheral vestibular disease could not be distinguished from normal subjects, and patients with cortical lesions fell mid-way between the extremes of normal subjects and those with brainstem disease. Although directional preponderance was related to the side of the lesion for both labyrinthine and cortical groups, the value of that indicator was questioned. Because the distribution of results for individuals in various groups overlapped considerably, the OKN test was found to be of value only in the context of the total oto-neurological test battery.

Optokinetic after-nystagmus

Optokinetic after-nystagmus (OKAN) is a continuation of optokinetic nystagmus (OKN) induced after the cessation of visual stimulation in complete darkness; this is known as OKAN I or post-OKN. After variable periods, it is followed by OKAN II; this is a secondary OKAN or reverse post-OKN. OKAN I has the same direction as the preceding OKN, whereas OKAN II is in the opposite direction. The duration of OKAN I is variable. In an effort to identify the mechanisms

of OKAN I and OKAN II, Waespe et al (99) studied the effects on OKAN II of brief periods of visual fixation during OKAN I. They found that OKAN I and OKAN II were influenced in a reciprocal way, i.e. OKAN I is reduced when OKAN II is increased. In those human subjects who exhibited no OKAN II in the controlled experiments, the suppression of OKAN I resulted in an OKAN II. They concluded that OKAN II depended upon the parameters of the preceding OKN stimulation and not upon the occurrence of OKAN I. Attempts to inhibit OKAN II by brief fixation periods resulted in a return of the OKAN II and a second maximum in its intensity; OKAN I showed little recovery. OKAN II was identified as a sign of central activity or counter-regulation which played a decisive role during all phases of OKAN.

Ireland and Jell (100) studied OKAN in patients with labyrinthine dysfunction. In patients with bilateral loss, there was markedly diminished or absent OKAN. In the unilateral group, when the OKN stimulus produced fast phases towards the affected ear, OKAN was markedly diminished or absent; it was replaced by a nystagmus in the opposite direction to the preceding OKN. This latter nystagmus was, in fact, identical to the spontaneous nystagmus present before the beginning of the test. The study demonstrated that OKAN is dependent upon a bilateral intact peripheral system, supporting the conclusions of previous investigators, and that unilateral loss affects OKAN in a predictable manner. The results from the patients with unilateral loss support the contention that two storage mechanisms are involved, one on either side of the brainstem, which are decoupled from each other (101). In addition, the reversed nystagmus appears to be an enhancement of the spontaneous nystagmus rather than OKAN II.

Pendular nystagmus

Pendular nystagmus is a sinusoidal oscillation which contains no saccades (no fast phases). It may be acquired or congenital and may be dissociated. It is indicative of an instability in a closed-loop control system. Pendular nystagmus may be purely horizontal, vertical, oblique, or may manifest itself as circular or elliptic nystagmus.

Gresty et al (102) discussed the characteristics, localizing value, and pathophysiology of acquired pendular nystagmus. They investigated 16 patients and reviewed 32 others reported in the literature. Two-thirds of their own patients had multiple sclerosis and one-third had cerebral vascular accidents or angiomas. The nystagmus could be monocular or binocular, conjugate or disconjugate, and could involve movements about single or multiple axes, e.g. circular nystagmus. Frequencies ranged from 2.5 to 6 Hz and amplitudes between 3 and 5°; all oscillations were highly synchronized. Somatic tremors of the upper limb, face and pallet, when present, were often at similar frequencies. The major ocular motor systems could be intact in these patients. The authors inferred that the mechanism responsible for acquired pendular nystagmus lies at a level close to the ocular motor nuclei such that it can have monocular affects without being part of the primary motor pathways. They suggested that the periodicity of the nystagmus most likely arises from instability in certain types of neuronal circuitry similar to that found in somatic tremors.

Periodic/Aperiodic alternating nystagmus

Periodic alternating nystagmus (PAN) (nystagmus alternans) is an extraordinary phenomenon in which a persisting horizontal jerk nystagmus periodically changes direction. There may be a fixed sequence consisting of approximately 90 s of nystagmus beating in one direction, 10 s of neutral phase in which the eyes stop, beat downward irregularly, or oscillate pendularly, followed by 90 s of beating in the opposite direction. In many patients, the timing is very asymmetric, but since the reversals continue to occur, it may be considered aperiodic alternating nystagmus (APAN). The waveforms of the slow phases will depend on the etiology in each case. PAN can be conceptualized as resulting from periodic shifts of the null zone of a manifest horizontal jerk nystagmus (103). PAN/APAN have been associated with congenital nystagmus, head trauma, encephalitis, syphilis, multiple sclerosis, spinocerebellar degenerations, and posterior fossa tumors and infarction.

Leigh et al (104) presented an excellent study of 3 patients with PAN by combining quantitative oculography, control systems analysis, simulation using a model, predicting behavior from the model, and verifying this behavior in the patients. The model successfully predicted a critical vestibular stimulus that would temporarily stop the PAN. This paper is a classic example of the application of feedback control systems analysis to a practical clinical problem and the paper's clarity allows me to recommend it even to those without a background in control systems. The optokinetic-vestibular model explained many of the normal phenomena that have been observed and, in addition, accounts for repair of spontaneous nystagmus in the dark and the reversal phases of postrotational nystagmus and optokinetic after-nystagmus. Since baclofen completely abolished the PAN in two of their patients in both light and darkness but did not improve their smooth-pursuit ability, they concluded that PAN and pursuit deficits did not have a single common cause. The authors hypothesized that baclofen decreased the gain of the internal positive feedback loop which is contained in the model and for which there is some anatomic and physiologic evidence.

Kennard et al (105) studied a patient with PAN which converted to periodic alternating gaze with radiotherapy and returned to PAN several days later. The periods of the PAN and periodic alternating gaze were the same. The patient had a tumor in the fourth ventricle as well as two lesions in the left frontal horn and left lateral ventricle. Baclofen did not alleviate the PAN. Because of the identical cycle time of both disorders, the authors hypothesized that the periodic alternating gaze demonstrated the underlying conjugate drifts of the PAN in which the normally occurring saccades were absent and suggested that this finding supported the shifting-null hypothesis (103) as the underlying mechanism for both PAN and periodic alternating gaze.

Larmande et al (106) reported on a completely different type of periodic alternating gaze: ping-pong gaze. This is a periodic alternation of gaze with a period of 3–5 s rather than minutes, as in both the above case and PAN. In addition to bitemporal, AC-coupled electro-oculography recordings of the eye movements, this paper contains pathology. Extensive edematous cerebral softening was observed in the hemispheres involving the anterior and middle cerebral arteries

and anterior choroidal arteries. There was also a pendunculopontile axial hemorrhage which destroyed the pontine tegmentum. No lesions were seen in the cerebellum, but the circle of Willis showed embolic occlusion of both middle cerebral arteries. In contrast to PAN and periodic alternating gaze of the type discussed above, which clearly involves the vestibular system, these authors suggest that this type of periodic alternating gaze is independent of the vestibular system. Unfortunately, they are searching for a 'generator' with a permanent rhythm rather than looking for instabilities in control loops to explain this oscillation. My opinions on the search for such 'generators' are contained in the section on Congenital nystagmus (p. 165).

A very interesting paper by Cross et al (107) reported a unique case in which PAN followed a subarachnoid hemorrhage with bilateral vitreous hemorrhages and which resolved after restoration of visual function by bilateral vitrectomies. Also unique was the upbeating nystagmus which was interposed between the right- and left-beating phases of the PAN. Although the paper mentioned ocular motor recordings, none were presented. This type of PAN is related to those which have been reported to appear with eye closure or in darkness only. Brought about by loss of visual input, it is the type which was modelled by Leigh and colleagues and discussed above; their patient had diminished pursuit and therefore lost the visual input of retinal slip. The curious finding of upbeating nystagmus during the PAN null is described in this paper as the 'missing link' between PAN, PAN with downbeating nystagmus during the null, and periodic alternating windmill nystagmus. The importance of visual input in these types of PAN must be contrasted with the congenital type which is augmented (not diminished) by fixation; this implies different mechanisms are involved in their production.

Rebound nystagmus

Rebound nystagmus is a gaze-evoked horizontal jerk nystagmus which fatigues and changes direction with sustained lateral gaze and/or horizontal gaze-evoked nystagmus which, upon refixation to primary position, transiently beats in the opposite direction (108). The slow phases are decreasing-velocity exponentials. Rebound nystagmus is often present in patients with parenchymal cerebellar disease, but normal subjects may demonstrate rebound nystagmus after prolonged far lateral gaze if the lights are shut off the moment the eyes are returned to primary position. Rebound nystagmus may be mistaken for periodic alternating nystagmus with asymmetric cycles (APAN).

Hood (109) recently presented some interesting observations on rebound nystagmus. As a result, he hypothesized that rebound nystagmus may actually be initiated by the saccadic fast phases, i.e. it may not be a true nystagmus at all. In support of this hypothesis, he shows a Figure which was the result of DC-coupled electro-oculography in which it appears, if one assumes the patient was actually foveating the target during the several-second period in which there was no nystagmus, that the saccades away from the target are initiating the oscillation. Hood states that normally electronystagmography is not helpful in establishing the actual position of the eyes relative to the target with any accuracy. That statement is correct and points out the need for more accurate methods such

as infrared reflection or the search coil. Further study of this phenomenon using accurate ocular-motility recording methodology is required to determine whether or not rebound nystagmus is a saccadic oscillation.

See-saw nystagmus

See-saw nystagmus is a conjugate, pendular torsional oscillation with a superimposed disjunctive vertical vector. The intorting eye rises while the opposite, extorting eye, falls. Torsional movements predominate in all fields of gaze, but the see-saw vertical feature may be restricted to the primary position or to downward gaze. Acquired see-saw nystagmus is associated with bitemporal hemianopias consequent to parasella tumors expanding within the third ventrical. Other common etiologies are upper brainstem vascular disease and severe head trauma. It is felt that see-saw nystagmus reflects diencephalic (thalamic) dysfunction, possibly of a pathway from the zona inserta to the interstitial nucleus of Cajal. See-saw nystagmus may be stopped by stereotactic destruction of the interstitial nucleus. Congenital see-saw nystagmus may manifest either in constant vertical disconjugacies without a significant torsional component, or in conjugate torsional nystagmus where the vertical component of the intorting eye falls while the extorting eye elevates (opposite to the acquired variety) (110).

Williams et al (111) presented EOG studies of a patient with see-saw nystagmus. Their simultaneous records of the horizontal and vertical movements of each eye showed both the see-saw movement in the vertical plane and a higher-frequency pendular oscillation in the horizontal plane. The phase relationship between the horizontal oscillations in each eye was variable. The see-saw frequency was approximately 1 Hz, whereas the horizontal pendular oscillations were 5 Hz. The patient had obstructive hydrocephalus, the lateral and third ventricles were markedly dilated and the fourth ventricle was normal and undisplaced. A second patient, with a thalamic infarct, showed see-saw nystagmus in upward gaze but horizontal rotatory nystagmus in lateral gaze. Based on the recordings of the first patient, it appears that both the vertical oscillation, which gave rise to the see-saw nystagmus, and the horizontal oscillation were independent in each eye, since the phase relationship of these oscillations was constantly changing. Thus, at times, the eyes moved up and down together and, at other times, in a see-saw manner; similarly, the eyes sometimes exhibited conjugate pendular nystagmus in the horizontal plane and, at other times, a horizontal pendular disconjugate nystagmus. The dissociated movements were damped during fixation and convergence (during reading). The effect of convergence on see-saw nystagmus is discussed in a paper by Mewis et al (112) in a case of see-saw nystagmus that developed after strabismus surgery. The nystagmus damped when the patient converged and looked down. The etiology of see-saw nystagmus is still not well understood but appears to include both central pathology near the third ventricle and sensory mechanisms such as acuity and convergence.

Upbeat nystagmus

Upbeat nystagmus is a vertical jerk nystagmus present in primary position with

downward linear slow phases and fast phases in the upward direction. Usually, the nystagmus is acquired and indicates structural disease; it may reflect drug intoxication. There are two types of upbeat nystagmus (113). The first type is a large-amplitude nystagmus which increases in intensity during upward gaze in accordance with Alexander's law; the second type is of small amplitude and decreases in intensity during upward gaze contrary to Alexander's law. Type 1 supposedly suggests a lesion in the anterior vermis of the cerebellum, and Type 2 suggests intrinsic medullary disease. An intermediate form behaves like Type 2, except that the nystagmus initially exceeds 5° in amplitude in primary position. This intermediate form is most commonly a manifestation of Wernicke's encephalopathy prior to the administration of thiamine. Since patients with intrinsic medullary disease have been demonstrated to have both Type 1 and Type 2 nystagmus, the localizing ability of this categorization is doubtful. Patients with upbeat nystagmus have been said to have a defect in upward pursuit but intact vestibulo-ocular movements in the upward direction. Thus, upbeat nystagmus has been called a pursuit-defect nystagmus. We no longer believe that pursuit-defect nystagmus has ever been proven to exist in any patient. In Volume 2, in the section on pursuit-defect nystagmus, I discussed the observations and reasoning supporting this opinion. Congenital upbeat nystagmus has been described but never recorded.

Cox et al (114) described a patient whose upbeat nystagmus changed to downbeat nystagmus with convergence. The patient developed the upbeat nystagmus while recovering from a Wernicke-Korsakoff syndrome. Unfortunately, no records were shown in this paper. What is described, however, is an upbeat nystagmus which obeys Alexander's law not only in the vertical direction, but also in he z-direction, i.e. toward and away from the patient. Apparently the upbeat nystagmus diminshed as the person converged on near targets until, at 30–33 cm, there was no nystagmus; at targets closer than 30 cm, a downbeat nystagmus developed which increased to the near point of convergence. Both amplitude and frequency of the downbeat nystagmus varied with convergence. Two other papers attribute upbeat nystagmus to a pursuit defect. Holmes et al (115) reported upbeat nystagmus (following meningitis) that obeyed Alexander's law in vertical gaze; no records were shown. Zumstein and Meienberg (116) described upbeat nystagmus in Werknicke's encephalopathy due to starvation. Unfortunately, nothing was said about the methodology employed in recording the eye movements, and the tracings shown are of such a slow time scale that they preclude any accurate analysis of the waveforms; those that can be seen appear to be decreasing-velocity exponentials, but it cannot be assumed that all slow phases were the same. Both papers discuss upbeat nystagmus in terms of a pursuit defect, and both presume defective upward pursuit because there are no slow eye movements in that direction. However, in the presence of vigorous downward slow phases, the normal pursuit system cannot cancel them out and produce upward tracking movements. Thus, one should not classify this pursuit as defective. As stated in the introductory paragraph to this section (as well as in Volume 2), we agree with the authors of the second paper that one cannot use the categories of Type 1 and Type 2 upbeat nystagmus to localize lesions.

Vertical nystagmus

Vertical nystagmus of either the jerk or pendular variety is nystagmus in which the trajectory of the eyes is up and down with respect to the head; this is irrespective of the tilt of the head. The slow-phase waveforms of jerk nystagmus, i.e. linear, decreasing-velocity or increasing-velocity exponentials, are of diagnostic importance. Specific types of vertical nystagmus are discussed in their respective sections.

Kattah et al (117) described 3 members of a family with hereditary cerebellar ataxia who exhibited primary-position vertical nystagmus. The nystagmus consisted both of upbeat and pendular waveforms. The recordings were made by electro-oculogram, the bandwidth was not given nor is it clear from the Figures whether or not the recording system was rectilinear; for these reasons, waveform analysis is difficult. The uniqueness of the family described in this paper is in the association of a cerebellar system disease and the early onset of spontaneous vertical nystagmus. Contrary to what is claimed, neither defective upward pursuit nor normal downward pursuit is shown in the Figures. The upward pursuit merely reveals the superimposition of the upbeat nystagmus, and the downward pursuit is due to suppression of the fast phases since the target velocity shown was equal to the slow-phase velocity of the upbeat nystagmus. It is not clear from the records of horizontal pursuit that the pursuit was truly 'jerky', as claimed, and did not result from cross-talk from the prominent vertical nystagmus. Smith et al (118) reported several cases of monocular vertical oscillations occurring in an amblyopic eye. Although the eye movements of these patients were recorded, no illustrations are presented in the paper; this is unfortunate for those of us who are interested in the specifics of various types of oscillations. Despite this, the paper contains a very good historical discussion of these types of cases, as well as a discussion of the successful therapeutic surgical intervention in one of the cases. This type of nystagmus is clearly secondary to visual impairment and disappears upon correction of the visual impairment; this is in contrast to congenital nystagmus which does not disappear when a patient's refractive errors are corrected. Stacy, in a paper on vertical nystagmus (119), mistakenly identified it as vertical ocular flutter. The tracing shown is of a 4–5 Hz pendular vertical nystagmus and not the saccadic oscillation which makes up flutter. The patient studied also had palatal myoclonus which was not synchronous with the vertical nystagmus. The description of these oscillations as saccadic in this paper are, in my opinion, unsupported by good data. They are continuous and of varying amplitude, and not the sporadic high-frequency, back-to-back saccades of flutter. No bandwidth for the position records is given nor for the velocity channel (which is not shown).

Vestibular nystagmus

Vestibular (labyrinthine) nystagmus is a jerk nystagmus which may be acquired due to central vestibular dysfunction, a peripheral (end-organ) vestibular disease or vestibular system plasticity reacting to dysfunction and producing compensatory nystagmus. It also may be induced (alternating current, caloric after, electrical, faradic, galvanic, perverted, pneumatic/compressive, positional/alcohol, postrota-

tional, pseudocaloric, or rotational/perrotary). Pathological vestibular nystagmus may be spontaneous or may be induced by having the patient adopt certain positions (positional) or shaking his head (head-shaking); in some patients, the act of changing positions induces the nystagmus rather than the position finally achieved (positioning). Positional nystagmus may beat constantly in the direction of the ground (geotropic) or it may beat in the direction opposite to the ground (ageotropic), regardless of head position. The slow phase of primary-position vestibular nystagmus is linear and the nystagmus increases with gaze towards the fast phase in accordance with Alexander's law. Vertigo usually coexists with the nystagmus. Acute lesions of the cerebellar flocculus (the vestibular cerebellum) can produce a similar nystagmus. In normal subjects, some degree of vestibular nystagmus may be induced when the labyrinth is stimulated with warm or cold water applied to the tympanic membrane. Direction of this nystagmus is such that the fast phase beats opposite to the side in which cold water is applied, or in the same direction as the side in which warm water is applied. Caloric nystagmus and caloric after-nystagmus (also called secondary-phase nystagmus) coexist with vertigo and past pointing. The direction of the vertiginous environmental movement (circular vection) is in the direction of the fast phase of the nystagmus. Pseudocaloric nystagmus is an appropriate cold caloric and an inappropriate warm caloric response from an ear with abolished vestibular function. Vestibular nystagmus is associated with Meniere's disease and many disease processes of vestibular end-organ or nerve. Spontaneous vestibular nystagmus is directed to the side opposite the lesion.

A subject of much speculation in the past few years has been the role of the pursuit subsystem in the cancellation of the vestibulo-ocular reflex (VOR). An excellent paper, which contains a model of cancellation of the VOR, was presented by D.A. Robinson at the recent International Symposium held in Wenner-Gren Center, Stockholm, Sweden (120). Since both failure of cancellation (in patients with intact pursuit systems) and ability to cancel (in patients who were unable to pursue) have been observed in neurological patients, the hypothesis that cancellation is due to superimposed smooth pursuit has been questioned. Robinson reviewed the relevant literature and suggested a model in which the VOR is cancelled by a signal proportional to the velocity of a planned head movement. Thus, VOR cancellation is not due to simple addition from the pursuit system but rather a signal which is switched on to effect the cancellation. In this paper, a model is used both to reconcile existing data as well as to suggest new clinical investigations.

Vilis and Hore (121) studied the nystagmus (presumably vestibular) produced by reversible lesions of the medial cerebellar nuclei in the alert monkey. They found that by cooling a region alongside the fastigial nucleus, a strong nystagmus was produced in the dark. Slow-phase velocities of 1-200°/s were elicited in the horizontal plane towards the side of the lesion. The maximum velocity of this drift was independent of position and degree of cooling. Vision abolished the nystagmus. They suggested that the fastigial nucleus is important in balancing the output of the paired vestibular nuclei, thereby preventing the imbalance which would otherwise result. Although this nystagmus was said to resemble that produced naturally by caloric stimulation, in our studies (122) we were able to demon-

strate the variation of slow-phase velocity with gaze angle (Alexander's law), and to correlate these data with our model of Alexander's law and vestibular nystagmus. Perhaps the high slow-phase velocities obtained by their technique precluded the more subtle effects of gaze angle; the slow-phase velocities of caloric nystagmus are usually 20-40°/s. Possibly related to Alexander's law variation of vestibular nystagmus are the findings of Nakao et al (123). In studying secondary vestibular neurons in cat, they found some neurons which responded not only to head velocity but also to eye position during slow eye movements. Perhaps these neurons are related to the gaze angle modulation of slow-phase velocity. They found rapid suppression of tonic activity in pre-motor neurons, and suggested that this contributed to the disinhibition and disfacilitation observed in the antagonistic pair of abducens motor neurons during the quick phases of vestibular nystagmus. They also concluded that secondary Type-I medial vestibular nucleus (MVN) neurons terminating in the abducens nuclei participated in the generation of the slow phase of vestibular nystagmus.

Because rotational testing is both more physiological and more easily quantified, it is the method of choice for studying and/or modelling the VOR. For the same reasons, there has been a dramatic increase in the number of clinical laboratories using these tests to evaluate their patients. As data have been gathered, it was only natural to compare rotational tests with the more common (and much cheaper) caloric tests. Jenkins et al (124) evaluated multiple-frequency rotational testing in patients with peripheral labyrinthine weakness. A destructive lesion of one labyrinth should result in two changes: the overall amplitude of the response should be reduced and there should be an asymmetry due to Ewald's second law. They found that rotational testing was not consistently effective in separating patients from normal subjects, due to the large variance associated with the latter group. Furthermore, the responses reflected the expected asymmetries only qualitatively. Because of the lack of statistical significance, they concluded that confirmation of Ewald's second law was only of theoretical and not of practical value. Similarly, phase-angle changes were not significant. The disappointing conclusion, when compared to caloric testing, was that patients who had statistically significant asymmetries during caloric testing often had rotational responses within the range of normal values. The ability to stimulate only one canal is a meaningful advantage for caloric testing over rotation. The reliability of the latter, however, makes it more desirable for follow-up testing required in studying the results of surgery or the progression of disease. Black and Wall (125) compared VOR and vestibulospinal screening tests. They found the latter slightly more sensitive (but not significantly so) than caloric tests for peripheral vestibular disorders. Neither caloric, rotation nor vestibulospinal tests were specific for Meniere's disease or benign paroxysmal positional nystagmus and vertigo. The caloric test's false-positive rate was the highest of the 3 for both groups. They concluded that the vestibulospinal test combined with either caloric or rotational testing increased the sensitivity for detection of peripheral disturbances (particularly in Meniere's disease). Carre (126) studied the value of electronystagmography in the medicolegal assessment of the sequelae of head injuries, and found an increase in the incidence of both position nystagmus and cervical nystagmus with age; asymmetry in the pendular tests however, showed no such trend. It was concluded that there was a statistically signifi-

cant correlation of this later test with a post-head-injury vertigo. Moser (127) also found the pendular test and electronystagmography to be useful in the medicolegal sense when evaluating patients complaining of dizziness. Toupet and Pialoux (128) studied vertical nystagmus induced by simultaneous bilateral calibrated caloric stimulation. They found that a calibrated injection of water at 44° C or 30° C for 30 s at a flow rate of 250 ml/min is insufficient to provoke a response in normal subjects. In subjects with central vestibular disorders, upward vertical movements were elicited with hot and downward with cold stimulation.

Dobie et al (129) compared electronystagmography and audiologic findings in patients with Meniere's disease. Neither directional preponderance nor the direction of spontaneous or positional nystagmus correlated at all with the side of the hearing loss. They discussed the surprising finding that there was no correlation between electronystagmography and audiometric findings in light of the strong correlations found by others. Meissner (130) studied the behavior of the nystagmus during a Meniere's attack. In most of the patients (28 of 37), the nystagmus was in the direction of the diseased ear; 14 showed reversal and 14 did not. The direction of the nystagmus is related to the potassium concentration in the perilymphatic space and the time course of the membranous potential change. In an electro-oculography study of patients with Machado-Joseph disease, Dawson et al (131) found defective caloric responses to be the best indicators. Defective sinusoidal tracking, optokinetic nystagmus, refixation saccades, and the presence of gaze-paretic nystagmus were also detected. Pouyat and Laurent (132) recommended electronystagmographic recordings of patients with chronic otitis. Using a pneumatic test, they found nystagmus beating to the opposite ear with both compression and decompression. They feel that this test is valuable in the prefistular state to detect what they called 'threatening nystagmus', which precedes the appearance of actual nystagmus. I would hesitate to call this situation, where no nystagmus exists, 'threatening nystagmus'; however, the test may be valuable in uncovering those at risk.

Since analysis of repetitive waveforms, such as those generated by vestibular or optokinetic tests, is eminently suitable for computer analysis, several papers per year usually appear. Particular programs evolve to satisfy the specific needs of a given laboratory. For that reason, it is not beneficial to the general reader to present a detailed analysis of each. For those interested in developing such a system, the referenced papers may be of interest (133–136).

Davey et al (137) found significant habituation of nystagmus responses to hot caloric stimulation in normal subjects. They concluded that the hot caloric test was not a suitable serial screening method for aminoglycoside vestibular toxicity. They suggested that any caloric test should be established in normal subjects before applying it as a serial screen. Kato et al (138) used a computer to analyze the fixation-suppresson of caloric nystagmus. They found slow-phase velocity to be the best parameter and were able to classify patterns of failure of fixation-suppression into 3 types. In a paper on failure of suppression of postcaloric nystagmus by fixation, Katsarkas and Kirkham (139) found that most patients had other ocular motor abnormalities as well. They concluded that failure of fixation-suppression is not a useful localizing sign by itself, but its presence should lead to a search for neurological disease, especially in the posterior fossa.

Chambers et al (140) recently studied a case of positional downbeat nystagmus. The nystagmus was induced by static tilt away from the normal upright posture or by linear acceleration of the head and by convergence. The authors suggest a role for the otoliths in the generation of downbeat nystagmus; their findings supported the interrelationship between the vergence system and the gain of the otolith-ocular reflex. The increase in the gain of this reflex with convergence could be responsible for those cases of downbeat nystagmus induced or exacerbated by convergence. Althaus and Gutierrez (141) studied the localizing significance of ear-dependent positional nystagmus of the labyrinthine type. They found little, if any, correlation between the unilateral ear-dependent positional nystagmus and proven unilateral labyrinthine dysfunction. They discussed their results in light of opposing views expressed in earlier reports. Several papers on positional nystagmus of central origin (142–144) make the important point that it may be impossible to differentiate the benign type from the more serious form at the initial assessment, and that further neurological evaluation is often warranted. Positional nystagmus may be the only symptom of central nervous system disease, such as multiple sclerosis or involvement of the posterior fossa.

When a subject is rotated about an earth-vertical axis at a constant velocity, the perrotary response lasts for 30–60 s and is followed by an oppositely directed postrotational response of comparable magnitude and duration. If, however, the subject is rotated about an axis off the vertical, the response has two components: a unidirectional nystagmus and a cyclic modulation which is a function of the instantaneous head position relative to gravity. Postrotational responses are either short-lived or absent. The critical physical variable in the latter instance is the rotation of a linear-force vector about the subject (the gravity vector). Papers by Goldberg and Fernández (145) and Raphan et al (146) contain good discussions of these phenomena as well as plausible hypotheses. Based on their studies in squirrel monkeys, Goldberg and Fernández (147) concluded that the directional information required to distinguish rotation direction is encoded across a population of otolith afferents in which the phase differences in the sinusoidal responses are possible sources.

Schmid et al (148) studied vestibular nystagmus modifications produced by fixation of both visual and non-visual targets. They feel that the smooth-pursuit system does not play any significant role in modifying the VOR, and postulated a model which utilized a 'central reconstructor' of target motion. Their conclusion about the main role of the smooth-pursuit system in both nystagmus suppression and full compensation is that it initiates these processes, and that its contribution is small at steady state. Toglia et al (149) studied rotational nystagmus suppression under various conditions of fixation and convergence. Since the nystagmus could be suppressed by light alone as well as visual stimuli, convergence and proprioceptive stimuli, they inferred that suppression involves brainstem reflexes rather than activity in the visual cortex. Kanzaki (150) studied the effects of fixation on vestibular rotational nystagmus. Five of his patients had congenital nystagmus; the inclusion of these patients in this group was unfortunate. The attempt to fixate is responsible for the generation of congenital nystagmus and, therefore, one cannot expect an absence of nystagmus during fixation despite the suppression of the vestibular component. Similarly, the so-called abnormalities in eye tracking

and optokinetic testing are due to the presence of congenital nystagmus. They did notice a change in the point at which the nystagmus reversed direction; it was found to differ under conditions of darkness and fixation. This null shift is found in many cases of congenital nystagmus, as has been discussed in that section of this Chapter. Mira et al (151) studied the effects of impaired suppression of vestibular nystagmus by fixation of both visual and acoustic targets in neurological patients. They found impaired suppression in cerebellar patients without correlation with visual smooth-pursuit defects. Acoustic suppression was equal to or weaker than visual suppression. In non-cerebellar patients, visual suppression was correlated with impaired smooth pursuit. In their study of vigilance and vestibular nystagmus, Ranacher and Moser (152) concluded that a mental arithmetic test combined with a key press would raise the patients' level of vigilance and maintain it during the examination. In addition to fixation, anti-motion-sickness drugs affect the nystagmus responses to angular acceleration and to optokinetic stimuli. Collins et al (153) found that commonly used anti-motion-sickness drugs reduced optokinetic nystagmus (OKN) but had little effect on vestibular responses during alert conditions. Under relaxed conditions, two of the drugs caused a significant decline in vestibular reactivity and the ability to fixate adequately during rotation. They concluded that the effects of a drug on nystagmus may be a poor indicator of its value in preventing motion sickness.

Postrotational nystagmus was studied in full-term and premature infants by Cordero et al (154). The results for both groups of children were similar in all variables of postrotational nystagmus, but the nystagmus was significantly greater in adults. All components of postrotational nystagmus, primary or secondary, can be identified in infants under 1 year of age, and are different from those observed in adults. Punwar (155), using 372 subjects between the ages of 3 and 10 years, expanded the normative data base for the Southern California Postrotary Nystagmus Test. Her results were consistent with the original normative data and suggest that this test may be used for subjects within this age range. Siegner et al (156) studied interrater reliability in this same test. They found a high reliability between experienced therapists for both normal and developmentally different children. They also pointed out the difficulties in testing the latter group. Watson et al (157) compared the Bender Visual Motor Gestalt Test, the Beery Visual Motor Integration Test, and the Southern California Postrotary Nystagmus Test. Their data provided evidence of a relationship between vestibular function, as measured by postrotational nystagmus duration, and ocular motor control in children with emotional disorders.

In studying visual–vestibular interaction as it relates to motion sickness in cars, Probst et al (158) found that the severity of the motion sickness was a function of the visual stimulus condition. They concluded that the best strategy to alleviate car sickness was providing ample peripheral vision of the relative moving surround. Schalén et al (159) studied vestibular nystagmus and OKN in neurological patients. They found that visual tests discriminated better between disorders of central origin than did the vestibular test. Also, visual suppression of caloric nystagmus was more frequently defective in patients who had exhibited decreased gains of OKN and smooth pursuit. Pfaltz and Ildiz (160) studied the effect of spontaneous vestibular nystagmus on OKN. They concluded that, because of the

large interindividual differences in vestibulo-visual interactions, actual OKN slow-phase velocity values obtained by visual stimulation are of limited diagnostic value in a single case. However, their data were able to distinguish between various nosologic groups of patients. They concluded that the most important diagnostic parameters of a pathologic fovea-retinal OKN are directional preponderance of slow-phase velocity and gain of OKN. Nystagmus, gaze shift, and self-motion perception during both head and neck rotation were investigated by De Jong et al (161). They found, suprisingly, that circular vection occurs more often during cervical than full-field OKN stimulation, despite the fact that the cervical-ocular loop has a much smaller gain than OKN. A greater gaze shift appeared in normal cervical responses than in normal labyrinthine responses. They concluded that cervical slow phases are added to the vestibulo-ocular signal and implied that ocular signs may be a poor measure of dizziness in cervical syndromes. In a subsequent study, Bles and De Jong (162) concluded that both the slow phases and saccades of cervical and vestibular responses add by vectorial summation, and that both the visually and cervically induced illusion of head rotation overruled the vestibular sensation.

OTHER OCULAR MOTOR OSCILLATIONS AND INTRUSIONS

Non-nystagmic ocular motor oscillations and intrusions represent solely saccadic or saccadically initiated instabilities. I have indentified 16 varieties of saccadic oscillations and intrusions which have been characterized in the literature by 42 different terms, including 8 which erroneously contain the term 'nystagmus'. This section contains discussions of recent studies of 8 types of saccadic oscillations and intrusions from the 16 originally identified in Table 2; they are in alphabetical order.

Bobbing

Ocular bobbing is a distinctive spontaneous ocular motor disturbance easily distinguished from downbeat nystagmus or ocular myoclonus. It is generated by fast downward jerks of both eyes (sometimes dissociated) followed by slow drifts to mid-position (163). It usually occurs in comatose patients who have extensive destruction of the pons; extrapontine compressions, obstructive hydrocephalus, and metabolic encephalopathy are occasional causes. Bobbing has been divided into 3 types (164). Typical bobbing involved both eyes and appeared in patients with paralysis of horizontal conjugate gaze. A uniocular type reflected coexisting unilateral third nerve paresis. The third category, atypical bobbing, included downward bobbing with convergence movements, asymmetric bobbing without associated ocular motor palsies, or bobbing with intact spontaneous or reflex horizontal eye movements. The pathophysiology of all forms of ocular bobbing is uncertain. Occasionally, inverse bobbing (the eyes jerk upward) has been seen in patients who are deeply comatose from metabolic encephalopathy.

Drake et al (165) reported a case of atypical ocular bobbing resulting from

metabolic encephalopathy. Neither neurologic nor postmortem examinations revealed any signs of brainstem dysfunction in sites associated with ocular bobbing. Brainstem auditory evoked responses, however, showed evidence of bilateral dysfunction of brainstem white matter. Safran and Berney (166) reported a case of inverse ocular bobbing which was synchronized with blinking. They postulated that inverse ocular bobbing resulted from the simultaneous occurrence of sustained downgaze deviation and spontaneous or reflex blinking.

Double saccadic pulses

Double saccadic pulses (DSP) are small back-to-back saccades which interrupt fixation, taking the eyes off the target and immediately returning them to the target. This type of saccadic intrusion is common in normal subjects (where the DSP may only be minutes of an arc in amplitude) and it has also been noted by this author as occurring in certain cases of congenital nystagmus.

Doslak et al (167) presented a case in which multiple double saccadic pulses occurred with other saccadic intrusions and oscillations. There appeared to be a continuum between individual DSP and bursts of them which are equivalent to flutter. This paper contains illustrations and discussions of various saccadic intrusions and oscillations, as well as the interrelationships among them. Selhorst et al (168) reported a patient who exhibited classic DSP. Since the patient had familial myoclonus, they suggested the movement be called 'myoclonic ocular jerks'. I believe this would lead to a confusion with ocular myoclonus and, furthermore, since DSP have been described in settings other than familial myoclonus, I suggest that the original name – 'double saccadic pulses' – be retained. DSP properly describes the eye movements without inferring etiology; this is especially important when multiple etiologies are possible.

Flutter

Ocular flutter consists of spontaneous back-to-back horizontal saccades which interrupt fixation. Flutter usually occurs in brief intermittent bursts and the eye movements are conjugate. Since the saccades are back-to-back, there are no intersaccadic intervals. Patients with flutter usually also exhibit dysmetria. Flutter and opsoclonus represent a continuum of ocular motor instability; patients often pass through phases of flutter when recovering from opsoclonus (the opsoclonus may re-emerge with upward gaze).

Toupet et al (169) described 3 cases in which ocular flutter is combined with both dissociated and conjugate opsoclonus. In the paper is a Table in which the authors attempt to define certain saccadic oscillations and intrusions. They refer to DSP as monophasic flutter and take great pains to differentiate flutter which has 2–3 etc. phases; this seems quite unnecessary. Similarly, large and small square-wave jerks (SWJ) need not be called by different names merely because of their amplitude; there is a continuum of amplitude ranges in patients with SWJ and among different patients. Flutter can occur before or after a saccadic refixation or during steady fixation; again, it is not necessary to give a different name to each place of occurrence. They refer to a saccade which is perfectly

orthometric but has a dynamic overshoot and an overshoot trajectory as hypermetric with a return glissade. The saccade shown is not hypermetric since the final eye position is on target. Flutter dysmetria is shown but this is called 'hypermetric flutter'; the description they give is incorrect for the same reason as the above description of an orthometric saccade. Finally, they differentiate between hypermetria with one or more hypermetric corrective saccades; again, this is quite unnecessary. In short, while all the variations they show (and many others which are not shown) do occur, it is certainly counterproductive to have a new name for every nuance.

Myoclonus

The term 'myoclonus' has been loosely applied to a variety of ocular conditions ranging from oscillations which are clearly nystagmus to simple square-wave jerks; it has even been equated to 'lightning eye movements'. Since ocular myoclonus is usually associated with myoclonic jerks of other structures of the body, I have chosen to list myoclonus under the heading of 'Other Ocular Motor Oscillations and Intrusions', despite the fact that the actual movement of the eyes may be a combination of a pendular nystagmus and a jerk nystagmus, where the saccades of the jerk nystagmus are synchronous with the myoclonic jerks of the involved body structures. Commonly involved with ocular myoclonus are the soft palate, tongue, facial muscles, pharynx, larynx and diaphragm. Palatal and oculopalatal myoclonus have a specific pathological correlate; it is pseudohypertrophy of the inferior olivary nucleus in the medulla. The myoclonic triangle involves 3 structures: the red nucleus in the midbrain, the ipsilateral inferior olive in the medulla, and the contralateral dentate nucleus of the cerebellum. They are connected by the central tegmental tract, the inferior cerebellar peduncle, and the superior cerebellar peduncle. It is pseudohypertrophy of the inferior olives secondary to involvement of these tracts which causes the oculopalatal myoclonus.

Spalton et al (170) reported on a patient with ocular myoclonus and oscillopsia. Unfortunately, the only tracing shown was quite noisy and no methodology was given (it was not stated how the eye movements were recorded, what the bandwidth of the system was, whether or not the electronics were AC-or DC-coupled or whether the tracing represented a single eye or a bitemporal recording). For these reasons, it is impossible to comment upon the waveforms shown in this tracing.

Opsoclonus

Opsoclonus (saccodomania) consists of rapid, involuntary, chaotic, repetitive, unpredictable, conjugate saccadic eye movements in all directions which prevent fixation and persist during sleep. The terms 'dancing eyes' and 'lightning eye movements' have been used to describe the eye movements of patients with opsoclonus.

Wertenbaker et al (171) reported the 15th autopsy case of opsoclonus. The paper contains a review and Table of the previous 14 cases and speculates about the anatomical localization of pathological abnormalities which have been seen with opsoclonus. The one speculation missing from this paper – and the one

which I feel is probably the most relevant – is the fact that most of these cases were not verified by ocular motility recordings and, therefore, the diagnosis of opsoclonus is suspect. Recordings are necessary to differentiate truly conjugate but chaotic saccadic eye movements from various other types of saccadic oscillations as well as some types of nystagmus; clinical examination is not sufficient for accurate diagnosis.

Psychogenic flutter

Psychogenic flutter, which includes both hysterical flutter and voluntary flutter, is a term I am introducing to replace voluntary 'nystagmus' (hysterical 'nystagmus', psychological 'nystagmus'). It was clearly shown by Schults et al (172) that so-called voluntary 'nystagmus' was not nystagmus at all but a series of back-to-back saccades, interrupting fixation, whose timing is such that the waveform traced out appears to be pendular. Since this oscillation is indistinguishable from flutter, I feel that the above terms are more descriptive of the actual oscillation and should be used instead of the previous terms. Psychogenic flutter, which has also been called 'ocular fibrillation' and 'ocular shuttering', is typically 8–23 Hz. It is a horizontal conjugate oscillation and each burst usually has a duration of less than 30 s.

Saccadic lateropulsion

Saccadic lateropulsion is a dramatic eye movement abnormality associated with lateral veering of body and limb movements. It has been reported in a patient with a left lateral medullary infarction (173). All saccades made to the left by this patient were very large (hypermetric), while those to the right were very small (hypometric). Even vertical saccades veered to the left along an oblique rather than the vertical path.

Nakada and Kwee (174) reported on a patient with a lateral lower pontine infarct that included the restiform body. The patient exhibited saccadic lateropulsion, asymmetric optokinetic nystagmus (OKN), and both downbeat rotary and upbeat rotary nystagmus. The patient's pursuit gain was low and pursuit was interrupted by square-wave jerks. Saccades to the left were hypometric and to the right, hypermetric. The hypermetria, however, was not classical; after the initial rightward hypermetric saccade, the target was reached by a series of hypometric leftward saccades. In contrast to the saccadic metrics, jerk-left OKN had larger fast phases than jerk-right. These differences are discussed in light of the directional asymmetry of the patient's vestibulo-ocular reflex (VOR). A tonic imbalance of the VOR is hypothesized to be interpreted by the patient as an actual head rotation which causes misinterpretation of actual head position and changes the internal representation of target position, shifting in the direction of head movement. The authors present this case in support of the theory of selective cerebellar inhibition of the VOR. Baloh et al (175) studied the eye movements of 6 patients with Wallenberg's syndrome. All their patients exhibited spontaneous nystagmus and lateropulsion along with ipsilateral facial numbness and ataxia. Saccadic eye movements away from the side of the lesion undershot the target,

while those directed towards the side of the lesion overshot it. Both smooth pursuit and OKN were asymmetric with slow eye movements towards the side of the lesion being greater than those away from the lesion. The authors discuss both a position and velocity bias in these patients, and speculate that the latter is due to asymmetric involvement of central vestibular pathways. The position bias is attributed to false internal reference with respect to gaze direction.

Square-wave jerks

Square-wave jerks (SWJ) (Gegenrucke, hopping 'nystagmus', 'lightning eye movements', and Zickzackbewegungen) consist of a pair of saccades which initially take the eyes off fixation by a few degrees and after a suitable latency (about 200 ms) return the eyes to the target. SWJ intrusions may occur in normal subjects (especially upon closure of the eyelids) or may represent pathology suggestive of cerebellar disease.

Sharpe et al (176) reported that 70% of 17 patients with acute or chronic focal cerebral lesions had SWJ. The SWJ in these patients were of lower amplitude than those in cerebellar system disease. They noted very short latency corrective saccades in some patients which indicates that they also had macro-SWJ. Low-amplitude SWJ can be detected clinically by fundoscopy. It is interesting to note that SWJ as well as macro saccadic oscillations (MSO), flutter and vertical nystagmus have been found in normal subjects by Hotson (177). These abnormalities were of lower amplitude than normally found when accompanied by ocular motor pathology. Because of the lower amplitude, the author has suggested that SWJ of such low amplitude be called 'square waves' and low-amplitude MSO be called 'saccadic oscillations'; he did not suggest a new name for low-amplitude flutter or vertical nystagmus. It is my opinion that the oscillations described are mechanistically the same as those found with pathology, regardless of their amplitude; the last thing we need (see Tables 1 and 2) are new names for the same eye movements. The value of this paper is in the finding of these oscillations at low levels in otherwise normal ocular motor control systems. Also evident in this paper, although not identified as such, are occurrences of double saccadic pulses. Baloh et al (178) noted SWJ induced by L-tryptophan. Both SWJ and hypometria appeared in a patient given a single 2 g dose of L-tryptophan; she had been pretreated with both a tricyclic antidepressant and a monoamine oxidase inhibitor. The movements disappeared within 24 h after the drugs were discontinued. Fisk et al (179) found SWJ in 4 patients with progressive supranuclear palsy and compared these patients with patients with Parkinson's disease, cerebellar damage, and a control group.

Levin et al (180, 181) have recently reported the presence of SWJ in the eye movements of schizophrenic patients. Because of the fortunate collaboration between Holzman and Stark, we in the ocular motor community can now redress a controversy that began 10 years ago with the publication in *Science* by Holzman of a paper which purported to show that schizophrenic patients have a basic defect in smooth pursuit (182). Because this paper was incomprehensible and it was impossible to dissociate so-called 'velocity arrests' from so-called 'positive saccades', Troost et al (183) stated that no such eye tracking abnormalities in

schizophrenics were documented by that paper. In the ensuing decade there have followed numerous papers, published in journals not critical from the ocular motor standpoint, which perpetuated the myth that schizophrenic patients had defective pursuit systems. Now, for the first time, thanks to the laboratory of Lawrence Stark, we can see that the deficit in schizophrenic patients is a saccadic deficit, i.e. SWJ. They are present during fixation and, of course, are superimposed on these patients' smooth pursuit. Although the authors persist in referring to the 'smooth-pursuit impairment' of these patients, it is clear that the basic smooth-pursuit system of schizophrenics is normal and, in some cases, of low gain bilaterally. Unfortunately, low gain can represent drug effects or inattention and it certainly is not specific for schizophrenia. Thus, the original criticisms of Troost et al (183) have finally been corroborated by good ocular motor recordings and future investigators can concentrate on the *saccadic* dysfunction exhibited by schizophrenic patients rather than looking for the non-existent defective smooth pursuit.

CONCLUSIONS

The volume of papers reviewed in this Chapter (and a volume of almost equal size not included) reflects the concerted efforts of many investigators to better understand the basic instabilities of the ocular motor system which result in nystagmus, saccadic oscillations and saccadic intrusions. Those papers supported by properly executed ocular motility recordings stand out from those containing only clinical observations, since they provide objective data that can be scrutinized by the reader and aid his search for this understanding. Indeed, good ocular motility recordings allow the reader to discount any misinterpretations that may be present in the body of the paper itself, and extract the meaningful information contained in the data. In closing, I would like to direct the reader to an excellent historical review of nystagmus in general and of optokinetic nystagmus in particular (184). This paper contains both quotes from several of the very early papers that examined nystagmus and the perspective of its senior author, Morris B. Bender, whose significant contributions to neuro-ophthalmology are as well known as they will be missed.

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