Pursuit and Optokinetic Responses in Latent/Manifest Latent Nystagmus

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Abnormalities of foveal smooth pursuit and the monocular optokinetic response (OKR) have often been reported in subjects with latent nystagmus (LN) and manifest latent nystagmus (MLN). This abnormality typically takes the form of a monocular asymmetry with a deficit in the response to nasal-to-temporal (N–T) motion in the visual field. Previous studies have each presented different interpretations of this finding, depending on whether the characteristics of the spontaneous oscillation were considered when analyzing the measured eye movement response: one report has suggested that these asymmetries are in fact the cause of the spontaneous nystagmus. In this study, pursuit and OKRs were examined separately and, when working synergistically and antagonistically, to attempt to overcome this difficulty. Results suggest that pursuit and the OKR could be symmetric in LN and MLN for both binocular and monocular viewing, which leads to the conclusion that the asymmetric patterns of response often reported in LN/MLN result from either shifts in the zone of minimum-intensity oscillation or from non-stimulus-specific increases in the spontaneous nystagmus. Investig Ophthalmol Vis Sci 31:1599–1614, 1990

Latent nystagmus (LN) is a binocular conjugate jerk nystagmus. It is classically reported as being absent when both eyes are fixating but is initiated by covering one eye. The initial eye movement has been described as a decreasing-velocity exponential slow phase taking the fovea off the target, which is then corrected by a saccade. The invariable feature of this horizontal nystagmus is that the fast phase is directed toward the fixing eye, regardless of gaze angle, or the direction and type of any ocular deviation present.

Total dissociation of the eyes to initiate the oscillation is not always necessary, and in most cases a spontaneous oscillation is seen when both eyes are viewing. This manifest latent nystagmus (MLN) occurs in people with strabismus and presumably results from the cortical suppression of the nonfixing eye: in contrast, it has been reported that some strabismics with LN and abnormal retinal correspondence do not show nystagmus when the eyes are in the tropic position.

In 1982 Kommerell and Mehdorn reported that there is a monocular asymmetry of the pursuit and optokinetic responses (OKRs) in LN/MLN. They found a low gain of the slow phase of the sawtooth response to a monocular N–T motion in the visual field and suggested that this deficit is in fact the cause of the LN/MLN. Their hypothesis was based on the premise that, when a normal subject views a stationary target, the N–T and temporal to nasal (TN) vectors of the pursuit and optokinetic (OK) systems are equal and balanced, so keeping the eyes stationary. In LN the N–T component is deficient, allowing unbalanced preponderance of the T–N vector, causing the eyes to drift nasally. This drift would be periodically interrupted by a resetting saccade, thus creating the rhythmic spontaneous oscillation in monocular viewing. In binocular fixation the T–N components of the response in the two eyes would balance and prevent instability. Other studies have reported similar results, and the monocular N–T asymmetry appears well established in the literature, although several different explanations for the resultant eye movement pattern have been advanced. The way in which these studies have accounted for the dynamic characteristics of the underlying nystagmus may contribute to these differences.

Previous evaluations of pursuit and OK function have involved assessments of the slow-phase velocity of the eye movements, and measurements of gain to express the match to target velocity, but other methods of assessment might usefully be considered. In everyday life, pursuit and the full-field OKR are often stimulated simultaneously but in opposite directions, rather than in isolation as is typical in labo-
ratory experiments. Consider the case of tracking a small interesting object against a detailed stationary background: as the fovea maintains fixation of the object in an accurate pursuit movement in one direction, the image of the background will be moving in the opposite direction across the retina, inducing an opposing OKR. In this situation the pursuit and OKR are antagonistic and the pursuit is the dominant component. It has been found, however, that an OKR to background motion does influence pursuit performance. An OK background moving in the opposite direction to the required pursuit impairs the response, whereas response velocity is increased when the two act synergistically. The effects of this OK background are often slight in normal subjects, particularly at low pursuit velocities, but are greater in those subjects who show poor response gain when pursuit is tested conventionally.12 In addition to its influence on the tracking of moving objects, the effect of an OK background on the subject's attempt to fixate a stationary object is also of interest. The mechanism of this suppression is not fully accounted for, but it has been suggested that the OKR is overpowered by a smooth pursuit command. Early open-loop experiments appeared to confirm this idea,14 but later work has shown that the pursuit/OKR interaction is not a straightforward linear summation.15 It is clear, however, that OK suppression is not simply the result of an attentional "switch," in which the presence of the fixation target totally shuts off the OKR.16 It may be expected, therefore, that subjects with deficient pursuit should not be able to exert such a significant suppressive effect on their OKR. Thus, in the current study conventional measurements of the response gain for the OK and pursuit systems were supplemented by additional tests. The suppression of the OKR was tested to look for evidence of an antagonistic pursuit response, and the pursuit/OKR interaction was investigated to look for evidence of any OK influence on the final eye movement response.

Materials and Methods

Infrared oculography (IRO) (bandwidth 50 Hz) was used wherever possible during this study, but because it is not linear beyond ±10° from the primary position, the lower sensitivity DC electrooculography (EOG) (bandwidth 22.5Hz) was used to record the movement of each eye individually for ocular responses outside this range. In each case the eye position signal was differentiated to allow identification and subsequent elimination of saccadic responses from the analyses. These experiments were all performed on subjects who had been confirmed as having LN or MLN by high-resolution eye movement recording on several different occasions and in whom the spontaneous nystagmus had been carefully defined.

This is important because estimates of the incidence of LN in different studies have varied widely, suggesting that different definitions of the condition have been used in the past. For example, Schmidt reported Lang's finding of 198 cases from 37,515 subjects, whereas Anderson identified 20 cases from 34,000 patients.18 LN/MLN may cause no subjective visual disturbance, so those who have it may be unaware of the condition; high-resolution objective eye movement recording is needed to confirm the presence of any binocularly manifest nystagmus not apparent by direct observation and to distinguish the condition from congenital nystagmus (CN).

Calculation of a meaningful slow component response velocity for pursuit eye movements depends on that slow phase being linear. In the case of LN/MLN, the slow phases have been reported by some workers to be decreasing-velocity exponential in form, whereas others have emphasized their variable nature. The latter has been confirmed in this laboratory where decreasing-velocity and linear slow phases have been recorded in LN/MLN. The subjects for this study were therefore chosen because more than 95% of the slow phases in their primary position spontaneous nystagmus were linear; this had been confirmed with the use of IRO on several occasions before the current investigation began. For all the experiments in this study, however, any nonlinear slow phases that did occur were identified and removed from the analysis.

Seven manifest latent nystagmats and two latent nystagmats with ages ranging from 11 to 55 yr participated in the different sections of this study. In addition, two subjects with MLN and aniridia were tested.

It is common for LN/MLN to be associated with strabismus: incidences of 95% and even 100% have been reported. It has also been suggested that strabismic subjects with amblyopia, but without LN/MLN, show abnormal pursuit and OKR. Thus, two unilateral strabismics with amblyopia, two alternating strabismics with normal acuity, and six subjects with no binocular anomalies ("normals") with ages ranging from 20 to 50 yr formed the control groups for this study.

Informed consent was obtained from all subjects before each procedure.

Large-Field OKR

Kommerell and Mehdorn suggested that in LN the asymmetric OKR and preexisting spontaneous nystagmus should summate, and the resultant OK nystagmus would then display one of two possible pat-
Pursuit Against a Small Field

Kelman et al have reported large directional asymmetries of pursuit gain in LN during monocular viewing. For 30°/sec constant velocity tracking, the gain was 1.2–1.4× higher when pursuing T–N compared with pursuing N–T while viewing with the better eye. For the worse eye the gains were 2–4× higher pursuing T–N (in the direction of the spontaneous slow phase). One of the possible explanations suggested for this asymmetry was a difference in the processing of visual information from nasal, compared with temporal, retina.

In the current study pursuit function was assessed in five subjects (four with MLN, one with LN) with the use of constant velocity bidirectional target motion ("triangular wave") in the horizontal meridian to measure the gain of the pursuit response (eye velocity/stimulus velocity) in the traditional manner. In all experiments in this study, eye velocity was measured by hand from eye position versus time traces, after nonlinear slow phases had been identified and rejected. Six age-matched normal subjects acted as controls. IRO was used to measure the horizontal position of each eye. The trial began with recording of the spontaneous nystagmus on viewing a stationary target (10° arc) on a television screen at a distance of 57 cm in the midline, and then target motion was initiated about the primary position. The overall extent of target motion was $7\frac{1}{2}$° right to $7\frac{1}{2}$° left of the midline. It was very important to measure the spontaneous nystagmus at the start of every trial because we have noted that a patient with MLN does not always exhibit the nystagmus in binocular viewing to the same degree: it can even disappear completely under some stimulus conditions. The subject viewed the target binocularly and monocularly, and velocities of target motion from 3° to 18°/sec were used in several discrete steps presented in random order with a rest between presentations. Response velocity was defined as the velocity of the longest continuous section of slow eye movement in each half-cycle. All subjects wore full refractive correction, and a chin rest was used, although complete head restraint was not attempted. The room lights were used during this experiment so background room features were visible to the subjects.

OKR/Pursuit Interaction

Optokinetic suppression was tested in all subjects by allowing fixation of a stationary red light emitting diode (LED) against the horizontally moving background. The movement of the background stimulus was exactly as described above for testing the large-field OKR.

A detailed investigation of pursuit ability on an OK background was performed in five subjects (two with MLN, one with LN, and two normal controls). A small green fixation target (2°) was superimposed on the striped background by means of a moving mirror
projection system. The pursuit target movement was from 15° right to 15° left of the primary position in a constant velocity bidirectional waveform (“triangular wave”) at velocities from 0° (stationary) to 60°/sec. The background could be as follows:

1. Completely absent so that pursuit was performed in total darkness (zero OK interaction);
2. Present but stationary (this stimulus condition also allows investigation of “pursuit against a large field” under analogous conditions to those used previously for “pursuit against a small field”);
3. Moving at 30°/sec L–R;
4. Moving at 30°/sec R–L.

In this group of subjects, OK suppression was also investigated during fixation of the target moving in low-frequency square-wave motion from 15° right to 15° left of the primary position. It has often been reported that LN/MLN varies with eye position according to Alexander’s Law, although this is not invariable.1 In addition, Yee et al have reported that in eccentric pursuit the eyes move faster toward the center of the orbit than away from it.21 To avoid these factors influencing the results, the response velocity was measured when the eyes crossed the midline. Average velocities from 2 to 10 cycles were used to calculate mean pursuit velocity in each direction: some cycles had to be eliminated from the analysis because of the occurrence of a saccade coincident with the primary position of gaze.

### Results

#### Large-Field OKR

Two types of horizontal OKR were identified among the ten nystagmats tested. The characteristics of the response were not qualitatively different whether the spontaneous nystagmus was classified as LN or MLN or whether aniridia was also present.

**Type 1:** Type 1 was seen in five subjects and followed previously reported characteristics of the OKR in LN. The binocular response was approximately symmetric, whereas the monocular T–N response had slow phases in the normal direction but was of more variable gain than that shown in normal subjects. The monocular T–N response velocity typically remained stable throughout the presentation even though the stimulus velocity was increasing.

**Type 2:** Type 2 was seen in five subjects and appeared to show responses in the incorrect direction that could not be explained as a continuation of the spontaneous nystagmus summated with a deficient or absent N–T OKR. The subjects displayed a mon-

![Fig. 1](image-url)
ocular T–N OKR of variable gain in the correct direction, whereas the N–T response was in the incorrect direction. In fact, the N–T slow phases did not just show a continuation of the spontaneous nystagmus, but a considerably larger response in the “incorrect” direction (Fig. 2). This could be explained in several different ways: as a “reversed” response, being caused by an OKR in the incorrect direction adding onto the spontaneous nystagmus, or as an enhanced spontaneous nystagmus with or without the addition of an N–T OKR.

In the subjects with a Type 2 response, the binocular OKR was also often asymmetric and in two cases was reversed in both directions of stimulation at some of the velocities tested (Fig. 3). It seems most unlikely that this resulted from a genuine reversal of the response and in fact the most reasonable explanation is that it resulted from voluntary changes in the state of fixation. Thus, there is no true “binocular” response, and fixation alternates between “right monocular” and “left monocular” even though both eyes are open. This is supported by the finding that the incorrect direction of the binocular OKR was not consistently present in all trials or for every velocity tested in a particular direction. For example, the response to R–L target motion could be right beating (that is, in the correct direction) and then part way through the trial change suddenly to left beating (an anomalous response).

Division of the group of subjects into these two types on the basis of the OKR may be age related: no subject in the Type 1 group was younger than 20 yr of age, whereas no subject of Type 2 was older than 15 yr old.

The results described in this study cannot be attributed directly to the presence of amblyopia or strabismus in the nystagmas. The control subjects with amblyopia and/or strabismus tested under the same conditions showed no asymmetry of the OKR, although the gain of the response was often low (Fig. 4).

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**Fig. 2.** The mean slow-phase eye velocity (deg/sec ± 1 SD) in a subject with MLN in response to horizontal optokinetic stimulation of various velocities from R–L (filled circles) and L–R (open circles). Stimulation was binocular (B), right monocular (R), and left monocular (L). The spontaneous oscillation slow phase before target motion began is represented as a positive (same direction as ensuing stimulation) or negative (opposite direction to ensuing stimulation) response to zero stimulus velocity. The spontaneous oscillation was below the resolution limit of the EOG recording equipment, which was adjusted to low gain to record the extremely high amplitude of response (note scale on ordinate). This subject shows a type 2 response.
Fig. 3. Tracings of the nystagmic response before (a, stationary field) and during (b, moving field) horizontal optokinetic stimulation at various velocities from R-L and L-R recorded by EOG. Stimulation was binocular, and it can be seen that the elicited response is in the incorrect direction except for 10°/sec R-L stimulation. It is noteworthy that the spontaneous oscillation is very irregular, and does not show the classic jerk waveform typical of LN/MLN. However, this is characteristic of the waveform seen when the subject is relaxed and not fixating a critical visual target (See Discussion).

Pursuit Against a Small Field

For normal subjects under these conditions, a smooth continuous bidirectionally symmetric eye movement response with a gain close to one would be expected. The pursuit response of the nystagmats, however, always showed the superimposed jerky nystagmic movements characteristic of the spontaneous oscillation, but these were modified in their slow-phase velocity from that typical of primary position gaze. In each case any slow-phase response in an inappropriate direction was plotted as negative.

The responses fell into the following two categories.

Type 1: In four subjects (all aged 20 yr or older) the binocular pursuit was symmetric in response velocity, but the monocular response showed an N-T deficit, with the slow phases occurring in response to N-T stimulus motion being approximately equal to the slow-phase velocity of the spontaneous nystagmus (shown as zero stimulus velocity) (Fig. 5, subject aged 50 yr). This is suggestive of a minimal or zero N-T pursuit response being summed with the continuing spontaneous nystagmus and is analogous to the Type 1 OKR described above. The T-N response velocities were somewhat variable, and, although there was certainly some increase in response velocity as the stimulus velocity increased, there did not appear to be a consistent relationship between the two.

If the latent component was very small, the N-T slow phases were often in the correct direction, but reduced in velocity compared with a normal response (Fig. 6, subject aged 20 yr).

Type 2: This response was seen in only one subject. Here the binocular response exhibited symmetric response velocities, but the monocular response did not show the simple N-T deficit of the Type 1 subjects. During left monocular viewing (Fig. 7, subject aged 11 yr) the T-N slow phases showed considerably greater response velocities than those required to produce precise target following. In addition, there was not a simple deficit of N-T response because the N-T slow phases did not just show a continuation of the spontaneous nystagmus, but an enhanced response in the “incorrect” direction. This could be described as a “reversed” response, being caused by a pursuit response in the incorrect direction adding onto the spontaneous nystagmus. Alternatively, it may merely result from an N-T pursuit response in the correct direction in conjunction with an enhanced spontaneous nystagmus.

Pursuit Against a Large Field

Pursuit testing against a small field with stimuli presented on the television screen restricted the range of stimulus velocities that could be tested. It was therefore appropriate to examine a greater range of velocities to further assess the relationship between stimulus and response. This was achieved by asking the subjects to pursue a target against a large-field stationary OK background. Under these conditions, stimulus velocities of up to 60°/sec were presented. Normal controls showed a definite reduction in gain of the pursuit response together with an increase in the variability of the response beyond 30°/sec (Fig. 8).

The “pursuit against a large field” responses of the three nystagmats (two with MLN, one with LN)
tested were all of Type 1, and a typical example is illustrated in Figure 9. The monocular response in each case was asymmetric, and in the example illustrated this asymmetry was different for the two eyes. The N–T response appeared to be a minimal response summated with the spontaneous nystagmus, whereas the T–N response was definitely present though somewhat variable. Thus, no subject showed the "reversed" (or Type 2) response in this experiment. This is particularly significant because the subject whose "large field" Type I response is shown (Fig. 9) displayed a Type 2 response for the lower stimulus velocities of the "small field" pursuit in the previous experiment (Fig. 7). This suggests that the Type 2 response is an artifact of the experimental conditions, occurring because high and variable spontaneous velocities can lead to the appearance of an enhanced pursuit response when the required response velocity is low.

**OKR Suppression**

The pursuit results suggested an N–T deficit of performance in monocular viewing, but it is very difficult to separate a true monocular asymmetry with a deficient (or even reversed) N–T response from a symmetric response affected by summation with the spontaneous nystagmus. Attempted OKR suppression may allow these two possibilities to be separated because, in attempting steady monocular gaze in the presence of an OK background moving T–N in the visual field, the subject uses an N–T pursuit command to overcome the involuntary OKR. If the N–T pursuit is deficient, then the OK suppression in the presence of T–N field motion should be ineffective. In this experiment with attempted steady fixation of a red LED against the moving OK background in a subject with MLN, we found no sign of the OKR appearing. It therefore appears that suppression is ef-
Fig. 5. (a) Tracings of the oscillation in right monocular (R) and left monocular (L) gaze for a subject with MLN when viewing a stationery midline target on a television screen (i), and when pursuing that target at constant velocity from 7.5° right to 7.5° left of the midline (ii, iii) recorded by IRO.

(b) The mean slow-phase eye velocity (deg/sec ± 1 SD), in the same subject, in response to horizontal pursuit against a small field at various velocities from R–L (filled circles) and L–R (open circles), recorded by IRO. Stimulation was binocular (B), right monocular (R), and left monocular (L). The spontaneous oscillation slow phase before target motion began is represented as a positive (same direction as ensuing stimulation) or negative (opposite direction to ensuing stimulation) response to zero stimulus velocity. In this case, no spontaneous oscillation was present in binocular viewing at the beginning of the experiment. This subject shows a type 1 response.

Fig. 10. Tracings of the oscillation in right monocular (R) and left monocular (L) gaze for a subject with MLN when viewing a stationery midline target on a television screen (i), and when pursuing that target at constant velocity from 7.5° right to 7.5° left of the midline (ii, iii) recorded by IRO. However, there are some bidirectional saccades apparent in the trace that may indicate inattention to the fixation target on the part of the observer, thus invalidating the results. It has been shown that inattention to the stimulus can affect the OKR, and thus this may not represent true OKR suppression.

To ensure that the subject was paying attention to the fixation target throughout the trial, OKR suppression was attempted again with the green moving fixation target reflected onto the striped background. This fixation target moved horizontally in low-frequency “square-wave” motion on the stationary striped background, and then the background started moving at 30°/sec either R–L or L–R. The intermittent saccades required to follow the target motion ensured subject attention, and the intervening steady fixations allowed examination of the spontaneous
Fig. 6. The mean slow-phase eye velocity (deg/sec ± 1 SD) in a subject with LN, in response to horizontal pursuit against a small field at various velocities from R→L (filled circles) and L→R (open circles), recorded by IRO. Stimulation was right monocular (R) and left monocular (L). The spontaneous oscillation slow phase before target motion began is represented as a positive (same direction as ensuing stimulation) or negative (opposite direction to ensuing stimulation) response to zero stimulus velocity. In this case, no spontaneous oscillation was present in right monocular viewing.

nystagmus during attempted OKR suppression. The traces were examined for any changes in spontaneous nystagmus to compare the “stationary” and “moving” conditions, but no such changes were consistently elicited. An example of the response for right and left monocular viewing is shown in Figure 11. Particularly significant are trials b and d, in which fixation was required against a background moving T→N in the visual field. This would be counteracted by N→T pursuit, and if such pursuit was deficient the OKR should be seen. No consistent change in the spontaneous nystagmus was detected in any subject under these conditions.

Pursuit/OKR Interaction

The results for the preceding experiments cannot allow differentiation between a true asymmetry (or even reversal in some cases) of the monocular OKR and an apparent asymmetry created by summation of the response with the existing or even enhanced spontaneous LN. To separate these alternative explanations, the subjects were asked to pursue a small foveal fixation target against a stationary and moving OK stimulus, and these results were compared with the pursuit performance in the dark (no background). This experiment was performed on five subjects (two with MLN, one with LN, and two normal controls).

The pursuit performance of each eye in each direction was therefore tested under four different conditions. In darkness the pursuit system is acting alone with no enhancing or antagonistic influence from the OK system. As the eye pursues a target from L→R (for example) against a stationary striped background, the image of that background must move over the retina from R→L. This constitutes a mildly antagonistic interaction of the OKR with pursuit. The moving striped background provides a more robust interaction with the pursuit response—either enhancing when moving in the same direction or antagonistic when moving in the opposite direction. In LN/MLN, however, if there is little or no N→T OKR, the pursuit response would presumably be essentially the same against both stationary and moving backgrounds.

The responses of each of the nystagmats tested were qualitatively similar, and an example is shown in Figure 12. Of particular interest is the comparison between b and d because the only difference between these conditions is the N→T motion of the OK background; however, this is obviously having a significant effect on both N→T and T→N pursuit. The N→T OK background enhances N→T pursuit performance and diminishes T→N response gain, and thus it appears that an N→T OKR is present to some extent in all these subjects.

Discussion

A summary of the characteristics of large-field OKR and small-field and large-field pursuit responses in LN/MLN when tested conventionally is presented in Table 1. The number of subjects in each group, and their age range, is also shown.

The results of this study suggest, however, that subjects with LN and MLN do not have a genuine N→T OK deficit. Any apparent asymmetry or reversal of the monocular OKR revealed by conventional methods of analysis appears to result from the summation of the OKN with the spontaneous oscillation (with the latter being changed in some way by the stimulus). Any binocular OKRs that were “reversed” appear to be caused by a voluntary change to right or left monocular fixation (Fig. 3).

The pursuit responses against both a small field and a large field recorded in this study, and analyzed in terms of the slow-phase velocity, show the often reported difference between the N→T and T→N directions. There is some suspicion, however, that these responses are not truly representative of the real performance of the pursuit system. A response classified as Type 2 on small-field pursuit and Type 1 on large-field testing was found in one subject, and this dependence of the response on the experimental conditions suggests that it owed more to the spontaneous oscillation than to true pursuit performance. In addition, when evaluating the efficiency of the pursuit system by the way in which it contributes to suppres-
Fig. 7. (a) Tracings of the oscillation in right monocular (R) and left monocular (L) gaze for a subject with MLN when viewing a stationary midline target on a television screen (i), and when pursuing that target at constant velocity from 7.5° right to 7.5° left of the midline (ii, iii) recorded by IRO.

(b) The mean slow-phase eye velocity (deg/sec ± 1 SD) in the same subject, in response to horizontal pursuit against a small field at various velocities from R–L (filled circles) and L–R (open circles). Stimulation was binocular (B), right monocular (R), and left monocular (L). The spontaneous oscillation slow phase before target motion began is represented as a positive (same direction as ensuing stimulation) or negative (opposite direction to ensuing stimulation) response to zero stimulus velocity. In this case, no spontaneous oscillation was present in binocular viewing. This subject shows a type 2 response.

Analyzing Pursuit in the Presence of Spontaneous Nystagmus

If pursuit performance appears symmetric, and yet analysis of the slow-phase velocity suggests asymmetry, it is clear that an alternative method of analysis is needed to reveal true performance. In a novel approach to pursuit analysis in nystagmats, Dell'Osso has pointed out that the only time the retinal image is on the fovea in a nystagmat (CN, LN, or MLN) is when the visual axis is temporarily motionless at the end of a fast phase, before the next slow phase causes it to drift off target.26 For normal subjects the aim must be to keep the target on the fovea at all times during tracking, but in a nystagmat perfect pursuit would involve maintaining the target on the fovea only during these foveation periods. If one imagines a jerky spontaneous oscillation superimposed on a smooth ramp, then the result for the nystagmat will be representative of very good tracking, although it

sion of the OK signal, there was no evidence of any deficiency (although this test is qualitative rather than quantitative).

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Fig. 8. The mean pursuit response velocity against a large-field OK background (deg/sec ± 1 SD) for a normal subject in right monocular (R) viewing. The dashed line represents “perfect” performance with a response gain of 1. The more variable and less accurate following as the stimulus velocity increases is shown. Filled circles indicate the response for a target moving R-L in the visual field, and open circles show L-R stimulus motion, recorded by EOG. (Half-filled circles indicate the coincidence of filled and open circles.)

Fig. 9. The mean slow-phase eye velocity (deg/sec ± 1 SD) in a subject with MLN, in response to horizontal pursuit against a large field at various velocities against a stationary OK background from R-L (filled circles) and L-R (open circles), recorded by EOG. Stimulation was binocular (B), right monocular (R), and left monocular (L). The spontaneous oscillation slow phase before target motion began is represented as a positive (same direction as ensuing stimulation) or negative (opposite direction to ensuing stimulation) response to zero stimulus velocity. In this case no spontaneous oscillation was present in binocular or left monocular viewing at the beginning of the experiment. This subject, who demonstrates a type I response under these experimental conditions, is the same subject who showed a type 2 response on small-field pursuit (Fig. 8).

Fig. 10. Tracings of the binocular (B) (a, R-L; b, L-R) and left monocular (L) (c, R-L; d, L-R) OKR suppression in a subject with MLN recorded by EOG. The striped background was stationary at the beginning of the experiment and present throughout. The arrow indicates the start of the background motion. The LED fixation target was present throughout the trial.

would not appear to be so when analyzed for slow-phase velocity.

Thus, to assess the smooth pursuit performance in LN/MLN, the slope traced out during the successive
Fig. 11. Tracings of the saccadic tracking (30° R-L across the midline, recorded by EOG) by a manifest latent nystagmat of a target moving against a striped background that starts to move with a velocity of 30°/sec at the position indicated by the arrow. (a) R monocular viewing; background moves L-R (N-T). (b) R monocular viewing; background moves R-L (T-N). (c) L monocular viewing; background moves R-L (N-T). (d) L monocular viewing; background moves L-R (T-N). The gaze change of the spontaneous nystagmus is apparent: see for example the leftward eye position in (a), where the eyes are stationary (obeying Alexander's Law) but no consistent change with movement of the background is seen.

foveation points should be considered. A tangent drawn through these points represents the smooth pursuit response and is equivalent to the analysis of smooth pursuit in a normal subject.26 If the pursuit data for subjects with LN/MLN are reanalyzed in this way, the response no longer shows monocular asymmetry in any subject, although the gain of the response does show intersubject variability (Fig. 13). This appears to confirm a suggestion made by Dell'Osso et al, that there was no true loss of pursuit

Fig. 12. The mean slow-phase eye velocity (measured in degrees per second in the primary position) of the left monocular (L) pursuit response of a manifest latent nystagmat to a triangular-wave bidirectional fixation target moving 15° right to 15° left across the midline at velocities between 0 (spontaneous oscillation) and 60°/sec, recorded by EOG. The background to the target was varied between trials: (a) no background (in darkness); (b) stationary striped background; (c) moving striped background T-N at 30°/sec; (d) moving striped background N-T at 30°/sec. Filled circles indicate R-L and open circles L-R target motion in the visual field.
Table 1. Summary of response characteristics of subjects with LN/MLN to involuntary OK, small-field pursuit, and large-field pursuit stimulation

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<th>Type 1</th>
<th>Monocular</th>
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<td>Binocular</td>
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<tr>
<td>Large-field OKR</td>
<td>Symmetric</td>
<td>Zero or low gain</td>
<td>Variable gain</td>
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<td>(5 subjects ≧ 20 yr)</td>
<td>Symmetric</td>
<td>Zero or low gain</td>
<td>Variable gain</td>
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<tr>
<td>Small-field pursuit</td>
<td>Symmetric</td>
<td>Zero or low gain</td>
<td>Variable gain</td>
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<td>(4 subjects ≧ 20 yr)</td>
<td>Symmetric</td>
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</tr>
<tr>
<td>Large-field pursuit</td>
<td>Symmetric</td>
<td>Zero or low gain</td>
<td>Variable gain</td>
</tr>
<tr>
<td>(3 subjects ≧ 20 yr)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Monocular

|        |        |        |           |
|        |        |        |           |

N. nasal; T. temporal.

function in LN/MLN. It is not surprising that the gain of the response is variable or low, because the input to the pursuit system must be complicated by the presence of retinal image motion brought about by the spontaneous nystagmus. Nonetheless, it appears that subjects with congenital nystagmus are able to rank a wide range of stimulus velocities, at least in relative terms.

A symmetric pursuit response could be produced in two ways: either as indicated above by the superimposition of a "normal" pursuit response and a spontaneous oscillation, or by a saccadic tracking in conjunction with the LN/MLN. Saccadic tracking in the absence of pursuit seems unlikely in this case because of the ability of the nystagmat to suppress the OKR; this could not be achieved by the saccadic system. Purely circumstantial evidence also exists that subjects with LN/MLN display no difficulty in everyday tasks that demand high-quality pursuit (for example, sports).

Thus, it seems that the final response represents the summation of a symmetric pursuit and the spontaneous nystagmus, often allowing accurate foveation to occur. The linear slow phases of the resultant eye movement, however, obviously do not simply represent a continuation of the previous LN/MLN sum-

Fig. 13. The mean response velocity (degrees per second ± 1 SD) for pursuit against a small field in left monocular viewing for R–L (filled circles) and L–R (open circles) target motion in the visual field, recorded by IRO. The results for two different observers (a, b) with MLN are illustrated. The slow-phase velocity of the pursuit response was measured as the slope of the tangent through the foveation points of the waveform.
Table 2. Theoretic calculation of change in spontaneous nystagmus slow-phase velocity during intended left monocular pursuit in a subject with MLN

<table>
<thead>
<tr>
<th>Intended response velocity (deg/sec)</th>
<th>Total measured slow-phase velocity (deg/sec)</th>
<th>Theoretic spontaneous oscillation, slow phase (deg/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-L (N-T) pursuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>-2.57</td>
<td>-2.57</td>
</tr>
<tr>
<td>+10.8</td>
<td>-13.09</td>
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</tr>
<tr>
<td>+14.4</td>
<td>-11.13</td>
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</tr>
<tr>
<td>+18.0</td>
<td>-21.03</td>
<td>-39.03</td>
</tr>
<tr>
<td>L-R (T-N) pursuit</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>+2.57</td>
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</tr>
<tr>
<td>+18.0</td>
<td>+31.46</td>
<td>+13.46</td>
</tr>
</tbody>
</table>

R. right; L. left; N. nasal; T. temporal.

Spontaneous Oscillation Changes

The "Minimum-Intensity (M-I) Zone" Shift Hypothesis: Such a change in the spontaneous oscillation has also been reported in CN: the cause of this is a shift in the neutral zone in the opposite direction to the intended pursuit.30,31 The neutral zone is the gaze position at which the oscillation changes the direction of the corrective fast phase from right beating to left beating, this can occur at any gaze angle. It typically coincides with the null zone, which is the gaze angle corresponding to minimum intensity of oscillation. LN/MLN does not exhibit a true neutral zone in that respect because it always beats toward the fixing eye but often varies with gaze angle after Alexander's Law in which the slow-phase velocity decreases when gaze is in the direction of the slow phase.1 Therefore, if LN/MLN behaved like CN, during pursuit from T-N the M-I zone would shift temporally and the spontaneous oscillation would reduce in the primary position. On pursuing N-T, the M-I zone would shift nasally and the spontaneous oscillation would increase. The faster the pursuit, the greater would be the shift in the M-I zone. Thus, the slow phase of the oscillation seen on N-T pursuit should reflect an increased spontaneous slow-phase velocity summed with the intended pursuit; conversely, the following T-N represents a decreased spontaneous oscillation added to the pursuit signal. The final recorded slow eye movement velocity is equal to the sum of the velocities of the spontaneous oscillation and the intended pursuit. Hence, if we assume that the pursuit signal has been present and accurate during the tracking, we can subtract this from the total response to obtain a measure of the spontaneous oscillation slow phase.

A calculation such as this will obviously be inaccurate. First, it can only be attempted for pursuit against a small field where the range of velocities tested is such that it would be reasonable to expect accurate and consistent following in a normal subject. Also, we can only use mean slow-phase velocity in the calculation and cannot take account of the inherent variability of the response. Additionally, it must be considered that in CN the neutral zone shift is variable in extent for each subject and this could also be true (if a shift occurs at all) in LN/MLN.

A theoretic calculation of the change in the spontaneous oscillation slow-phase velocity was performed for the data derived from "pursuit against a small field" on intended monocular pursuit of a target moving N-T and T-N for the five subjects tested in this study. Intended response velocity is assumed to be equal to stimulus velocity, and the spontaneous oscillation during fixation of a stationary target in the primary position is represented as "zero intended response velocity." Negative responses indicate an eye movement in the incorrect direction for that stimulus. In two cases the "theoretical spontaneous oscillation slow phase" increased with pursuit in both directions. These subjects were 11 and 20 yr of age, and the

Table 3. Theoretic calculation of change in spontaneous nystagmus slow-phase velocity during intended left monocular pursuit in a subject with MLN

<table>
<thead>
<tr>
<th>Intended response velocity (deg/sec)</th>
<th>Total measured slow-phase velocity (deg/sec)</th>
<th>Theoretic spontaneous oscillation, slow phase (deg/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-L (N-T) pursuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>-4.72</td>
<td>-4.72</td>
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<td>+9.0</td>
<td>-5.63</td>
<td>-14.63</td>
</tr>
<tr>
<td>L-R (T-N) pursuit</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>+4.72</td>
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<td>+7.59</td>
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</tr>
<tr>
<td>+9.0</td>
<td>+9.96</td>
<td>+0.96</td>
</tr>
</tbody>
</table>

R. right; L. left; N. nasal; T. temporal.
result for the former is shown in Table 2. In an additional two cases the "theoretical spontaneous oscillation slow phase" changed in accordance with the prediction of a shifting M-I zone—decreasing on pursuit T-N and increasing on pursuit N-T—and was more affected by the faster pursuit velocities. These two subjects were 35 and 50 yr of age, and the result for the latter is shown in Table 3. The remaining subject (who was 30 yr old) showed both of these responses (one in each eye).

The "Concentration" Hypothesis: Clearly, the "M-I zone shift" hypothesis does not explain those responses that show a spontaneous oscillation increase with pursuit in both directions. We suggest that in these subjects (typically the younger ones) the changes in spontaneous oscillation resulting from the null zone shift are masked by an overall increase in the intensity of spontaneous oscillation during the pursuit arising from the increased difficulty of the task. This is analogous to the "effort-to-see" or "concentration" effect reported previously in CN,2.3 and such increases in the oscillation depend on psychologic factors rather than on the characteristics of the particular stimulus.32 The idea that such changes can occur in LN/MLN is supported by two pieces of evidence obtained from the current study. First, the OKR showed an age-related difference in response that could be explained by an enhanced spontaneous oscillation occurring in the young subjects as the visual task became more demanding. Second, it was noted that some subjects with MLN did not show spontaneous nystagmus on all occasions even though the viewing conditions were identical; sometimes the MLN was manifest binocularly, but at other times it was not, particularly when the subject was relaxed and not fixating any particular object. This was also evident even in monocular viewing.

An analogous argument concerning an M-I zone shift can be applied to explain the OKR in LN/MLN (at least for the older subjects with a Type 1 response). Although initially the recorded eye movements appeared to show monocular asymmetry, this was in fact the spontaneous nystagmus modified by the M-I zone shift produced by OK stimulation (as has been found in CN30.33) added to the (possibly symmetric) OKR. The interaction of the pursuit and OKRs indicated that a definite change occurred in the slow-phase velocity of the pursuit eye movement in the predicted fashion when the striped background was moving in the same or opposite direction to the intended pursuit. This applied equally, whether the OKR-stimulating background was moving N-T or T-N in the visual field, thus suggesting that the true monocular OKR is in fact symmetric.

The Type 2 OKR, usually seen in younger subjects, is probably explained by increasing spontaneous oscillation resulting from "concentration," regardless of the direction of stimulation.

In conclusion, the current study has suggested that the pursuit and OKRs in LN/MLN may be monocularly symmetric, or perhaps completely normal in some subjects. The superimposition of these responses and the spontaneous nystagmus means that conventional measures of slow-phase velocity do not reveal true pursuit/OKR performance. Alternative analysis methods suggest that apparent abnormalities recorded in the pursuit and OKR are in fact reflections of the spontaneous oscillation, and therefore cannot be causative factors in the genesis of the condition.

Key words: latent nystagmus, manifest latent nystagmus, optokinetic response, pursuit, monocular asymmetry

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