

Dynamics of Cover Test Eye Movements

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ABSTRACT

The dynamics of unilateral cover test eye movements, never before systematically investigated with an objective recording system, are shown to be more complex than textbook accounts of them. We administered the cover test to nine heterophoric subjects by means of electromechanical occluders. Eye movements were recorded using the infrared photoelectric technique. Saccadic and vergence movements of the fixating eye were observed in almost all records when the occluded eye was uncovered. These movements were found in esophores and exophores and in both large and small phoria cases. Such movements were previously described in other asymmetric vergence tasks and appear to obey Hering's law of equal innervation. Uncovering the dominant eye, in cases of clear dominance, resulted in shorter latency and larger amplitude saccades than did uncovering the nondominant eye. These large saccades were frequently of unequal amplitude in each eye. Trained subjects appear to use dynamic overshoots to increase this saccadic inequality and thereby attain vergence during saccades. Movements after the application of a cover to one eye, while grossly similar to textbook descriptions of them, are found to contain small vergence drifts and refixation (correcting) saccades in the nonoccluded eye.

Key Words: cover test, asymmetric vergence, dynamic overshoots, heterophoria, unequal saccades

The cover test is the most commonly used technique for the detection and diagnosis of heterophoric and strabismic oculomotor imbalance.^{1,2} The unilateral cover test, in which one eye is briefly covered and then uncovered, is used principally to reveal the presence of a strabismic deviation. The alternating cover test, in which the cover is repeatedly switched from one eye to the other, is used to quantify the deviation. This report concerns the dynamics of unilateral cover test eye movements in normally binocular patients.

The standard clinical descriptions of unilateral cover test eye movements^{1,2} assert that when one eye is covered (the "cover phase") it will deviate to its heterophoric posture, while the noncovered eye maintains steady fixation. When the cover is removed (the "uncover phase") the formerly covered eye regains fixation, and again it is assumed that the fixating eye does not move. The required movement is therefore an asymmetric vergence in which the "fixating" eye should remain steady while the covered eye performs the entire vergence. Such descriptions portray the static position of the eyes before and after occlusion, and not the actual trajectory of the eyes that lead to their static position. Thus, Griffin notes that a slight "flick" of the fixating eye may be noted in patients with large phorias.

If the fixating eye of heterophores made no movement during the cover test (i.e., in small heterophorias) then the cover test eye movement pattern would be in violation of Hering's law of equal innervation³ and run counter to a number of studies on asymmetric vergence eye movements.⁴⁻⁶ Because the intermittent occlusion of the cover test is a stimulus condition not previously used in asymmetric vergence studies, and because there are no reports available on the dynamics of cover test eye movements using a recording technique sufficient to resolve these dynamics, we decided that a reassessment of cover test eye movements using a high-speed objective recording technique was needed to resolve the question of the general conformity of

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unilateral cover test eye movements to Hering's law and to the known characteristics of asymmetric vergence eye movements.

Semmlow and Heerema⁷ measured, in normal observers, movements of the covered eye after a unilateral cover. Their method of applying the cover when the eyes are at the phoria position of gaze was intended only to demonstrate certain accommodative/convergence relationships, and limits the conclusions one may draw from their results about the normal dynamics of cover test eye movements. A few studies of cover test eye movement dynamics based on visual observations have been published.⁸⁻¹⁰ Pickwell^{9,10} noticed, in patients with high heterophoria, movement of the noncovered eye during the uncover phase of the test. He found that the fixating eye frequently makes a saccade away from the point of regard which is followed by an approximately symmetric vergence movement back to the point of regard. This first movement of the fixating eye, named the "irrelevant" movement or "flick" by Pickwell¹⁰ as it did not reflect the demand of the stimulus, was assumed to be an expression of Hering's law. Pickwell¹⁰ noted that irrelevant saccades were not reported in earlier studies.

Irrelevant movements have been demonstrated in a variety of experiments on asymmetric vergence.⁴⁻⁶ The vergence stimuli in some of these experiments are aligned on the visual axis of one eye, thus demanding no change in the position of the aligned eye when vergence demands are varied. We shall compare the cover test response to these types of eye movements.

Ono and Nakamizo⁴ studied asymmetric vergence eye movements throughout a spectrum of accommodation and convergence conditions. They found movement of the aligned eye in almost all trials. The magnitude of this saccadic movement varied with the different conditions. One extreme of the asymmetric vergence spectrum is represented by the Johannes Mueller experiment^{4,5,11,12} in which the eye not aligned with the far and near targets is constantly occluded. This case is known as the "accommodation only" condition⁴ as no disparity-driven vergence is possible with one eye occluded. Most of the movement is performed by the covered eye, which manifests an asymmetric vergence which appears to violate Hering's law. The results show, as noted by Ono and Nakamizo,⁴ that the "fixating" eye moves toward the occluded eye, but its movement is much smaller. Thus, some type of irrelevant or Hering-type movement is maintained even under these monocular conditions. The accommodation-only condition is similar to the cover phase of the cover test by virtue of the absence of binocular visual control over either movement. The cover

phase differs from the accommodation-only condition because of the absence of any accommodative stimulus change in the cover phase.

The other extreme of the vergence eye movement spectrum demands a vergence response despite a constant accommodative demand, and is known as the "disparity-only" case. Disparity-only stimuli may be presented haploscopically,^{4,13,14} or by the interposition of a prism before one eye (e.g., the 4 Δ base-out test). Hering's law of equal innervation seems to hold best for the disparity-only condition because almost every response is found to contain an irrelevant saccade of large magnitude. Many of these disparity-only movements also show what appears to be a non-Hering's law inequality of "irrelevant" saccade amplitude⁶ in which the covered eye generates the large saccade. (Kenyon et al.^{15,16} have also observed this inequality in accommodation-only experiments.) These unequal saccades have the effect of reducing the fusional vergence response required to meet the disparity demand in the disparity-only case.

The vergence demand of the uncover phase of the unilateral cover test is very similar to the asymmetric disparity-only demand. In both cases, the accommodative stimulus is held constant and the disparity of the target, subtended entirely at the nonaligned eye, is the only vergence stimulus. These two vergence stimuli differ qualitatively only with respect to the intermittency of binocular vision in the cover test. If the absence of binocular vision does not affect the subsequent eye movements in the uncover phase of the cover test, then we can expect these movements to be similar to those found in the disparity-only condition and that the irrelevant saccade characteristics should be present in small phoria cases as well as large phoria cases. Both of these expectations were realized.

METHODS

Nine subjects, aged 24 to 35 years, all had normal binocular vision and 6/6 (20/20) or better visual acuity while wearing their habitual distance corrections. One was tested while wearing soft contact lenses, two wore spectacles, and the remaining six subjects were nearly emmetropic. Six subjects were exophoric and three were esophoric. Informed consent was obtained from all subjects before their participation.

Eye movements were recorded using an infrared photoelectric technique.¹⁷ The electronics for the photoelectric eye movement monitor were assembled in our laboratory. Infrared sensors and emitters were fitted to an adjustable spectacle frame mounting device (Rehder Devel. Co., Castro Valley, CA). A small bite-board was

used to stabilize both head movements and the viewing distance of 30 cm. For calibration purposes the subjects tracked a horizontally moving spot on a cathode ray tube. The spot slowly oscillated over a 16°-wide path. The spot was driven electronically by a triangular wave signal while the experimenter set the gain and baseline of the monitor for each eye. The triangular wave tracking calibration technique proved to be superior (i.e., easier and more accurate) to the commonly used three point staircase calibration technique. Eye movements during calibration and cover test were monitored on-line with a Tektronix 502A dual-beam oscilloscope. After calibration the cathode ray tube beam was defocused and positioned at the center of the screen to retro-illuminate a 6/9 (20/30) Snellen letter as the accommodative target of the cover test. Ten successive cover-uncover recordings were taken for each eye. The first eye to be tested was randomly chosen. The eye was covered by an electromechanical occluder whose movement was initiated by a manual switch. The eye movements were monitored on the oscilloscope until the apparently full phoria posture was attained, after which the cover was removed. Eye movements were acquired by a Nicolet MED/80 digital computer which was triggered when the cover changed position. Eye movements were sampled at a rate of 500 samples/sec/eye for 2 sec after each cover position change. The data were stored on magnetic disk for later processing and plotting on a Hewlett-Packard 1035B X-Y plotter.

RESULTS

Typical cover test eye movements are found to be similar to other asymmetric vergence eye movements. The movements are a combination of vergence and saccade in both the fixating and nonfixating eye. The right and left eye contributions to the vergence movement are frequently unequal in both the uncover and especially the cover phase. Cover phase saccades are invariably equal in each eye. The magnitude of the uncover phase saccade is frequently unequal in each eye. These characteristics are seen in small phoria cases as well as large. Our results are presented according to the subject's heterophoria (eso or exo) and according to the type of vergence condition used (cover or uncover).

Exophores

The cover phase movement is usually much longer than the uncover phase movement, and in many cases the 2-sec recording period does not span the entire cover phase response. In

these cases, the experimenter waited (up to 8 sec in some cases) for the completion of the eye movement, as determined by on-line monitoring, before initiating the uncover phase. This intermission in the recording resulted in the eye position discontinuity at the transition from the cover to uncover phases in the figures (see, for example, Figs. 1a and 2a). In most cases, the cover phase vergence is very asymmetric, and occasionally takes place entirely within the covered eye without an associated saccade (Figs. 1a and 2a). Most cover phase movements, however, include irrelevant saccades of 1° or less. Upon occlusion both eyes diverge, resulting in a fixation error which leads to a corrective saccade. The remainder of the movement follows a pattern of entirely asymmetric divergence. Many times, however, the divergence refixation cycle is repeated two or more times (Figs. 2b, 3, and 4a). These cover phase saccades are a presentation of Hering's law: the point of fixation demands no movement from the nonoccluded eye, and yet it participates in a partial yoked vergence and versional eye movement with the covered eye.¹² The saccades are of nearly equal magnitude in right and left eyes, and the significant inequality of interocular saccadic amplitude that we observed in the uncover phase is absent.

Saccades play a far more prominent role in the uncover phase of the cover test. Many movements feature large amplitude early-onset conjugate saccades with amplitudes very different in the two eyes. Responses featuring late-onset saccades show smaller saccadic amplitude and less interocular amplitude inequality. When saccadic amplitudes are unequal, the covered eye always produces the larger response. The data of subject MS (Fig. 1; Table 1) illustrate this correlation of saccadic amplitude with latency. When the right eye is uncovered (Fig. 1a), an early onset saccade precedes most of the vergence, the former being unequal while the latter is relatively symmetrical. When the left eye is uncovered (Fig. 1b), the relatively late-onset saccade of smaller amplitude is preceded by a very asymmetrical vergence. Subject AS shows this behavior even more explicitly than subject MS. Uncovering the right eye (Fig. 2a) results in an early onset saccade which is twice as large in the right eye as in the left, and which is followed by a symmetrical vergence. Uncovering the left eye (Fig. 2b) results in a completely asymmetrical vergence with no associated saccade (i.e., an infinite saccadic latency).

All six exophoric subjects presented only early-onset saccades (with relatively symmetric vergence) when one of their eyes was uncovered, and either early or late-onset saccades when the

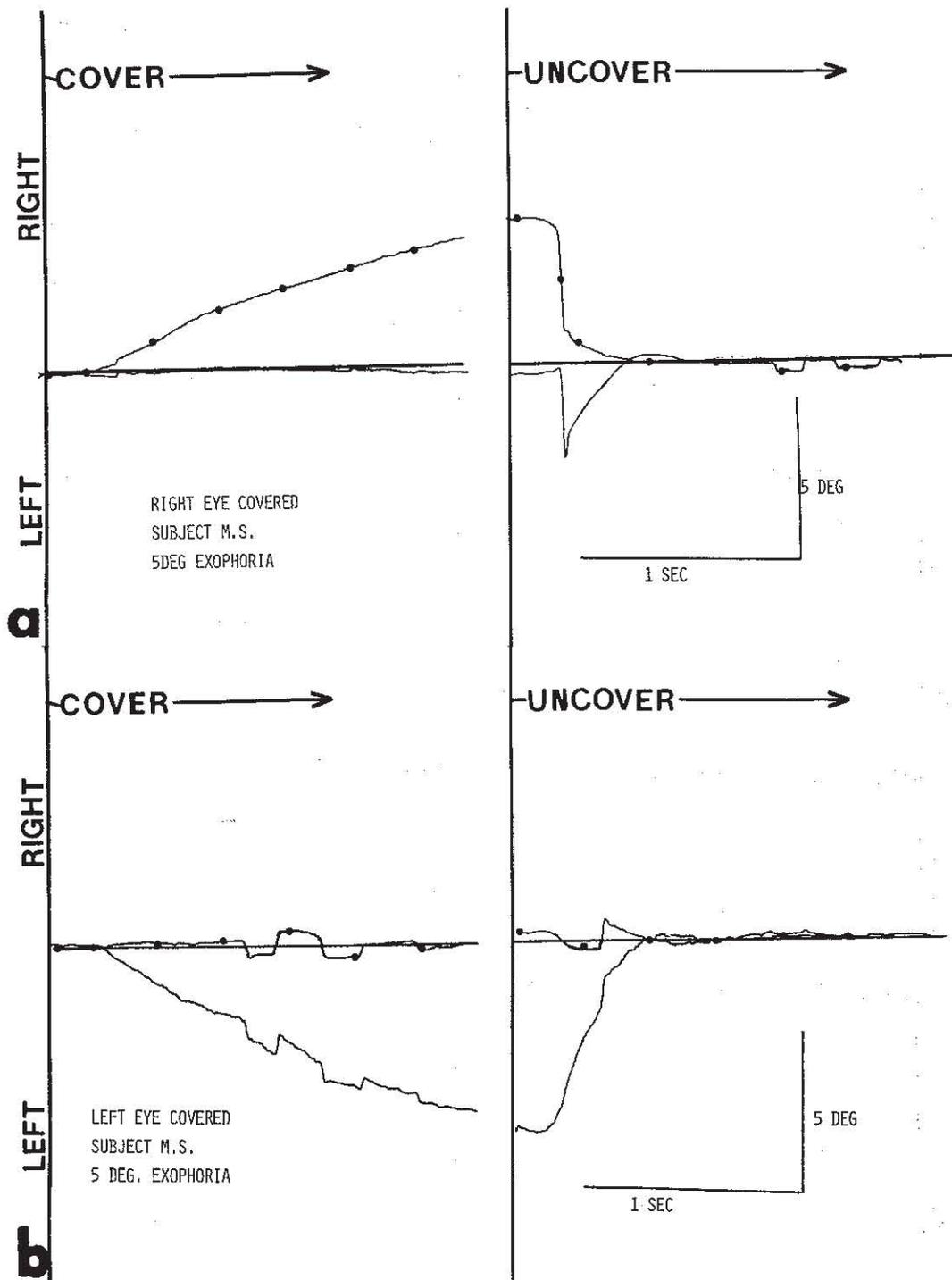


Fig. 1. Subject MS, a 5° exophore, shows a saccade free cover phase response and a short-latency saccade uncover phase response when the dominant right eye is tested (a). Note overshoot of uncover phase saccade and the reduction of the disjunctive demand by the unequal saccade of right and left eyes. Cover testing of the left eye (b) produced a cover phase response free of vergence drifts and corrective saccades in the fixating eye, but upon which were superimposed several incidental search saccades. The uncover phase response shows an asymmetrical vergence followed by a small saccade of long latency. In this figure and all the other figures, lines with dots = right eye and without dots = left eye. The left half of each record shows the cover phase response, and an upward movement of a trace represents a rightward movement of the eyes. Each phase represents 2 sec of time and the vertical bar indicates the eye movement amplitude calibration. A variable interval of time (up to 8 sec; not shown on records) separated the cover phase and uncover phase responses.

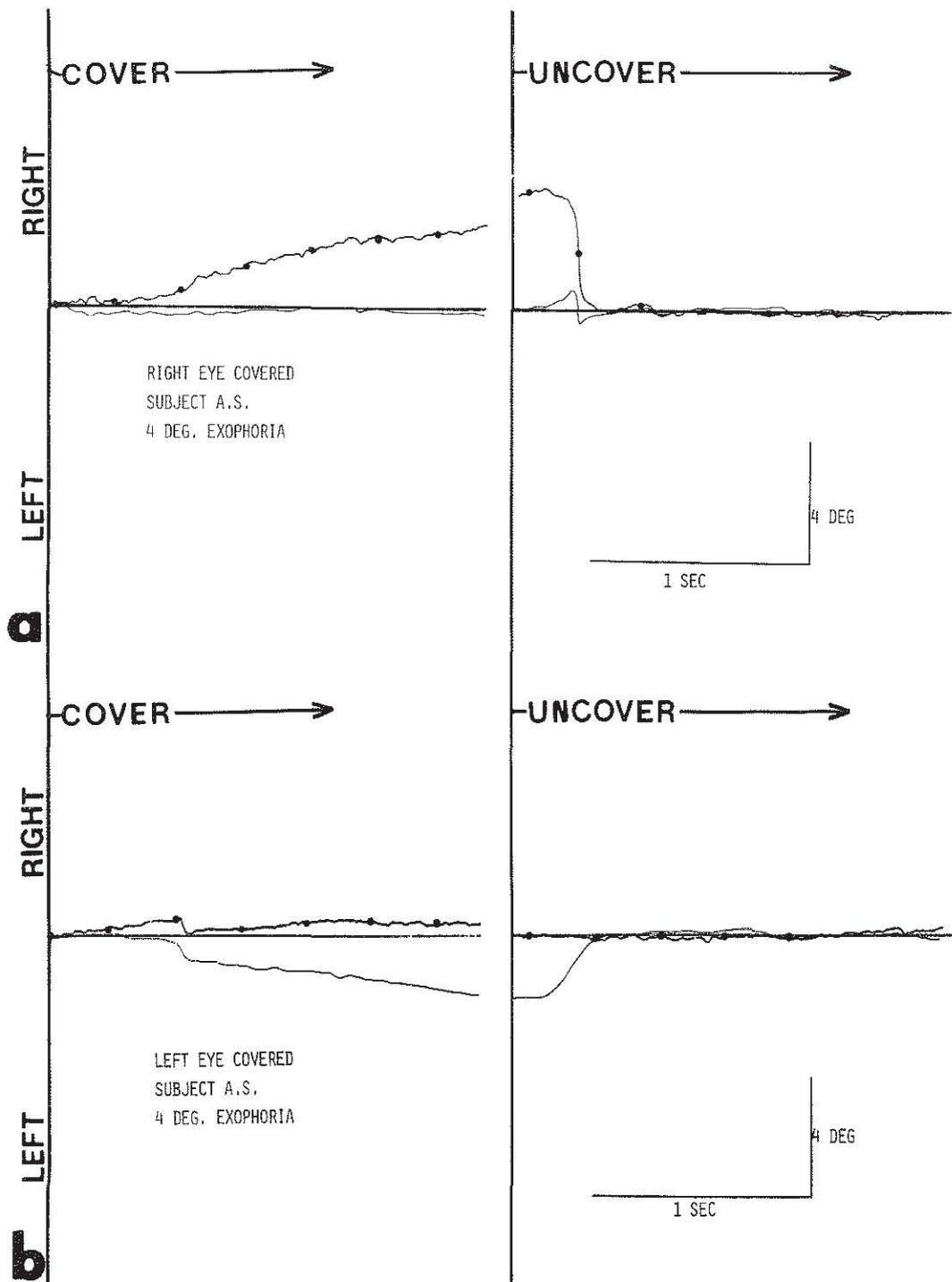


FIG. 2. Subject AS, a 4° exophore, shows a saccade free cover phase response and a very large amplitude inequality of the early saccade uncover phase response of the right eye in the cover phase (a). The left eye cover test (b) shows a vergence drift and a corrective saccade of the right eye in the cover phase response, and a rare smooth and saccade free response of the left eye in the uncover phase.

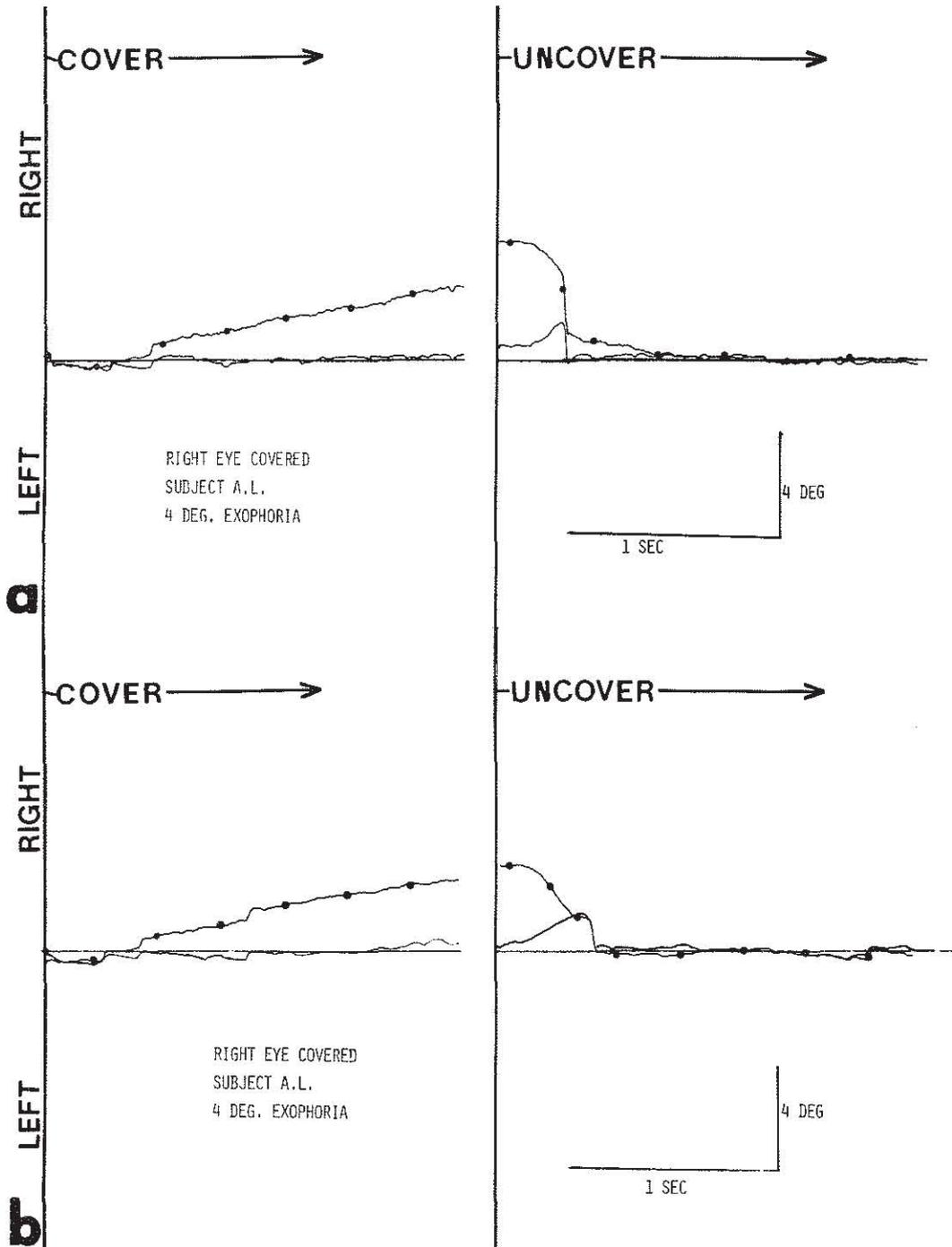


FIG. 3. Subject AL, another 4° exophore, showed both short-latency (a) and long-latency (b) uncover phase saccade responses when uncovering the right eye. This mixture of long- and short-latency uncover phase responses to repeated testing was typical of subjects with normal binocular vision and no obvious ocular dominance.

other eye was uncovered. That eye which always generated early-onset saccades was also the dominant eye in those four subjects with clear ocular dominance. These early-onset saccades

also tended to be larger in overall amplitude in the two eyes.

Saccadic amplitude inequality contributed significantly to our subjects' disjunctive re-

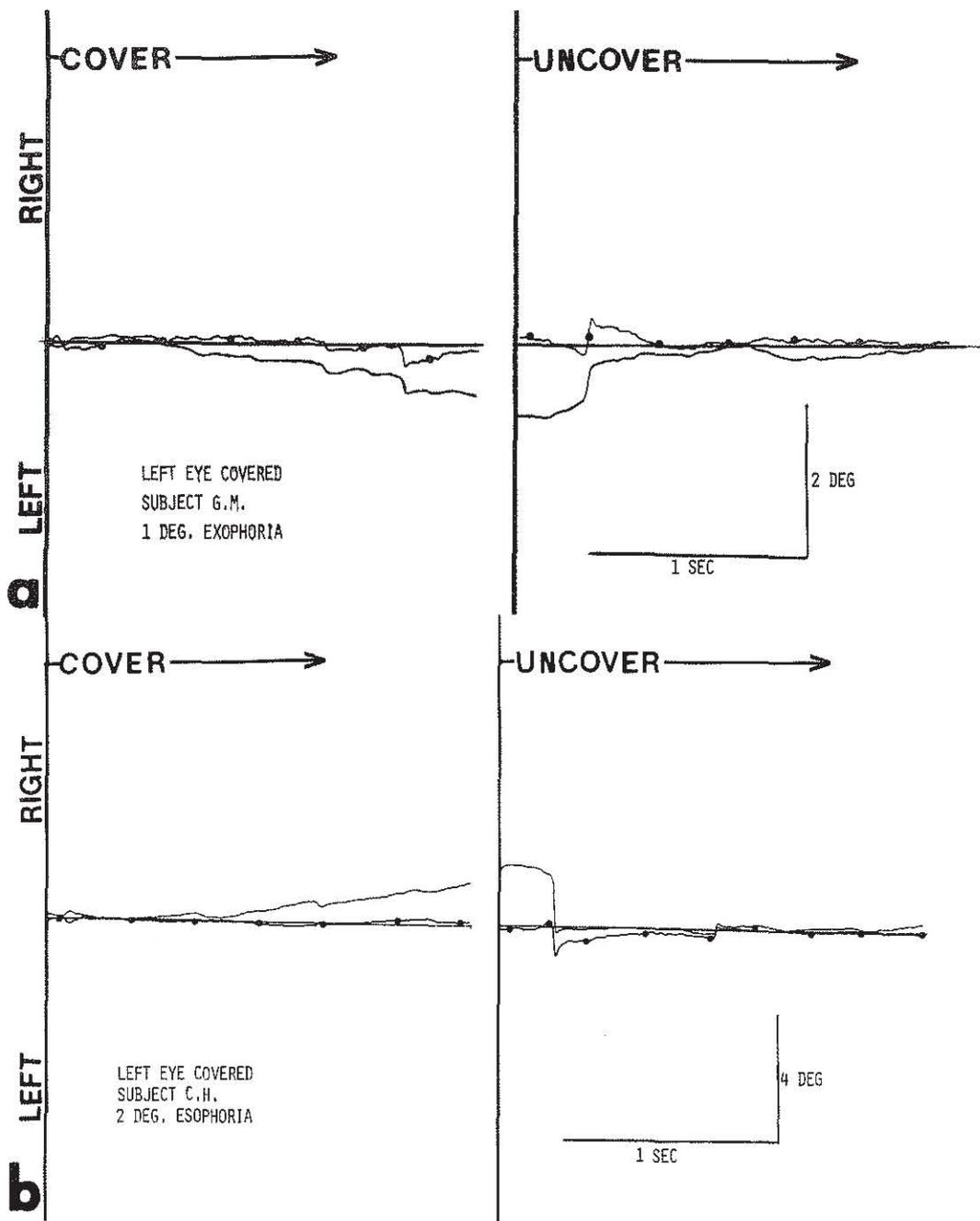


FIG. 4. Subject GM (a), a 1° exophore, shows vergence drifts and multiple corrective saccades on the cover phase and an early saccade on the uncover phase. Subject CH, a 2° esophore, shows a saccade free response during the cover phase (b). Uncovering the left eye results in a response with a short-latency unequal saccade. Note the small dynamic overshoots for both subjects.

response to the disparate stimulus of the uncover phase. The saccadic component of early-saccade responses (Figs. 1a, 2a, and 3a) brings the eyes back to a position of approximately symmetric vergence demand, but its inequality also results in a significant reduction of the disparity de-

mand of the stimulus. On the other hand, the relatively rare saccade-free response (Fig. 2b) follows the movement trajectory described in textbooks, and thus places the entire burden of the disparity demand upon the smooth vergence eye movement system. Responses of late sac-

TABLE 1. Differences in uncover phase parameters of the two eyes compared for two 5° exophoric subjects with clear right eye dominance.^a

	Subject MS		Subject SG	
	Right Eye uncovered	Left eye uncovered	Right eye uncovered	Left eye uncovered
Saccadic latency ^b (msec)	243 ± 29 (10)	430 ± 117 (10)	314 ± 35 (9)	613 ± 165 (7)
Relative saccadic response ^c	0.69 ± 0.13 (10)	0.23 ± 0.11 (10)	0.93 ± 0.12 (9)	0.14 ± 0.09 (9)
Saccadic inequality ^d	0.65 ± 0.13 (10)	0.67 ± 0.13 (10)	0.32 ± 0.09 (9)	0.68 ± 0.24 (7)
Peak vergence velocity (deg/sec)	18.93 ± 4.94 (10)	19.10 ± 6.23 (10)	8.05 ± 1.47 (9)	14.86 ± 3.48 (9)
Time to fusion ^e (msec)	595 ± 49 (10)	755 ± 141 (10)	679 ± 115 (9)	851 ± 65 (9)

^a Each box shows the mean, ± 1 SD, and, in parentheses, the number of records analyzed. Some parameters were measured in less than 10 records when artifact obscured that parameter.

^b Measured from the time of exposure of the covered eye.

^c Ratio of the largest saccade in response to the full phoria deviation.

^d Ratio of the smaller saccade to the larger saccade.

^e Time where the disparity has been reduced to 10% of its initial value after removal of the occluder.

cadic onset reveal small saccadic amplitude (Figs. 1b, 3b, and 4a). These saccades also serve to restore the eyes to a symmetrical convergence position, but due to their small size result in an insignificant reduction of the disjunctive demand. The disparity demand is being met predominantly by the vergence system in these two cases.

Because slow fusional vergence movements consume much more of the time required to attain bifixation than do uncover phase saccades, the reduction of stimulus disparity by an unequal saccade should shorten the time required to complete a response. Table 1 shows the response completion times of subjects MS and SG, defined as that time when the disparity has been reduced to 10% of its initial value. Subject MS displays a response completion time of 755 msec when his left eye (featuring late, small, and relatively equal saccades) was uncovered, and 595 msec when his right eye (early, large, and unequal saccades) was uncovered. This difference is significant at the 0.02 level ($t = 3.22$, $dF = 9$). Subject SG showed a similar result: a response completion time of 851 msec when the left eye was uncovered and 679 msec when the right eye was uncovered. This difference in response completion time is significant at the 0.01 level ($t = 3.68$, $dF = 8$). The other exophores could not be tested similarly for this time difference because of the mixture of early and late saccades within one of the two eyes, and the esophores could not be so tested because of the absence of late-onset saccades in their responses (see below).

Our argument that unequal saccades shorten

response completion time assumes that the smooth vergence velocities of unequal saccade responses are not greater than those of equal saccade responses. This assumption appears warranted for subjects MS and SG (Table 1). Subject MS showed no significant difference in smooth vergence peak velocity between right and left eye uncover phase responses. Subject SG showed significantly faster smooth vergence peak velocity when the left eye was uncovered. Despite this difference, the greater saccadic amplitude inequality from uncovering the right eye yielded a shorter response completion time than when uncovering the left eye.

Esophores

Saccadic eye movements appeared more frequently in esophoric than in exophoric subjects. During the cover phase, our three esophores usually exhibited several saccades per response. The convergence component of the esophoric cover phase response was much more symmetric than the divergence movement of the exophoric response.

Bidirectional multiple saccades were common in the esophores (Figs. 5 and 6) during the uncover phase. They resulted when the covered eye overshoot the target in the first saccade, requiring a corrective saccade in the opposite direction.

Our three esophoric subjects, unlike the exophores, showed no overall change of saccadic amplitude as the test was switched from one eye to the other, nor did they show any significant ocular dominance.

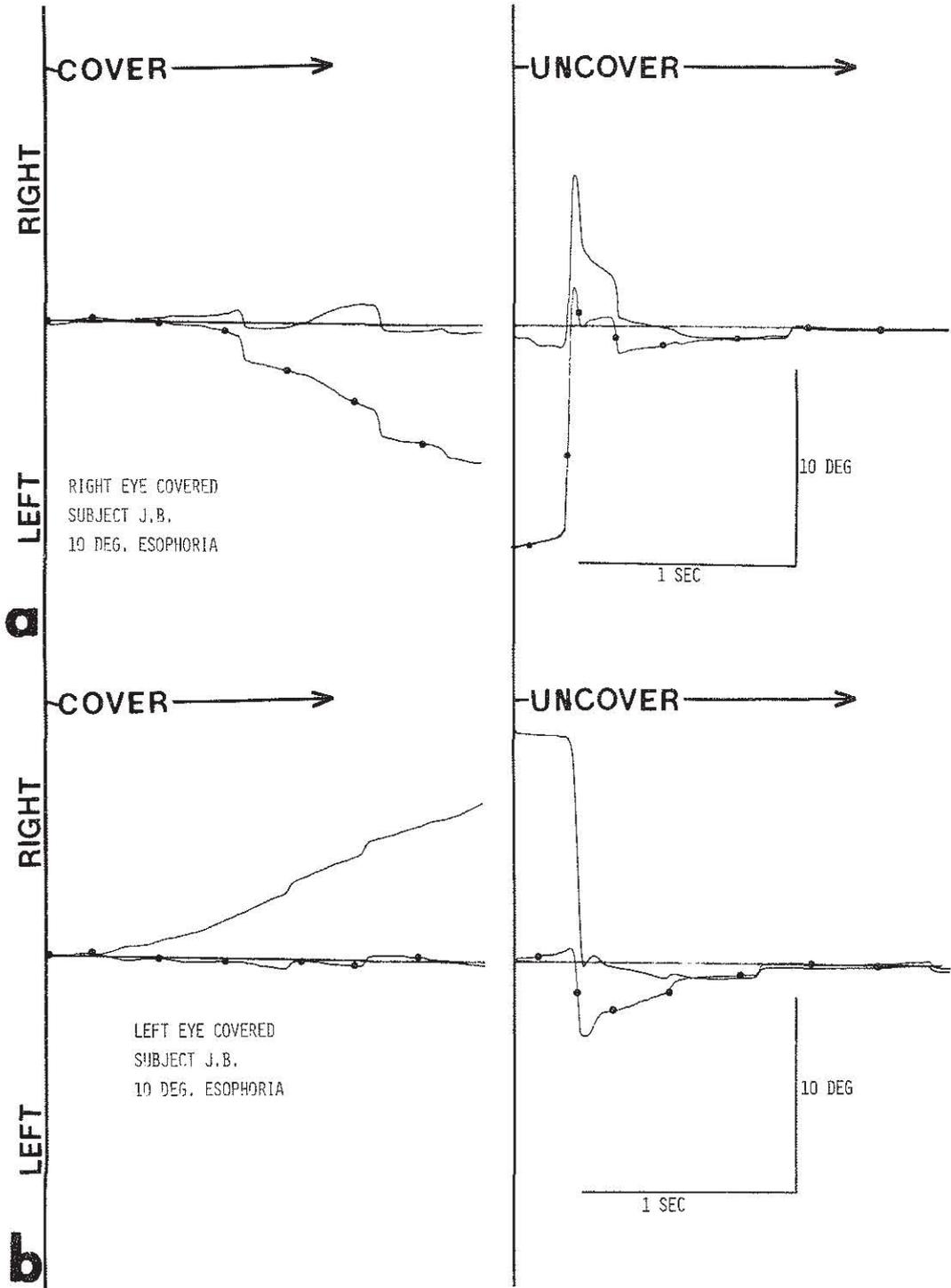


FIG. 5. Subject JB, a 10° esophore, clearly demonstrates unequal saccades and overshoots when uncovering either the left or right eye. Multiple drifts and corrective saccades of the fixating eye were common during the cover phase in this and other esophoric subjects. This subject generated bidirectional multiple saccades during the uncover phase.

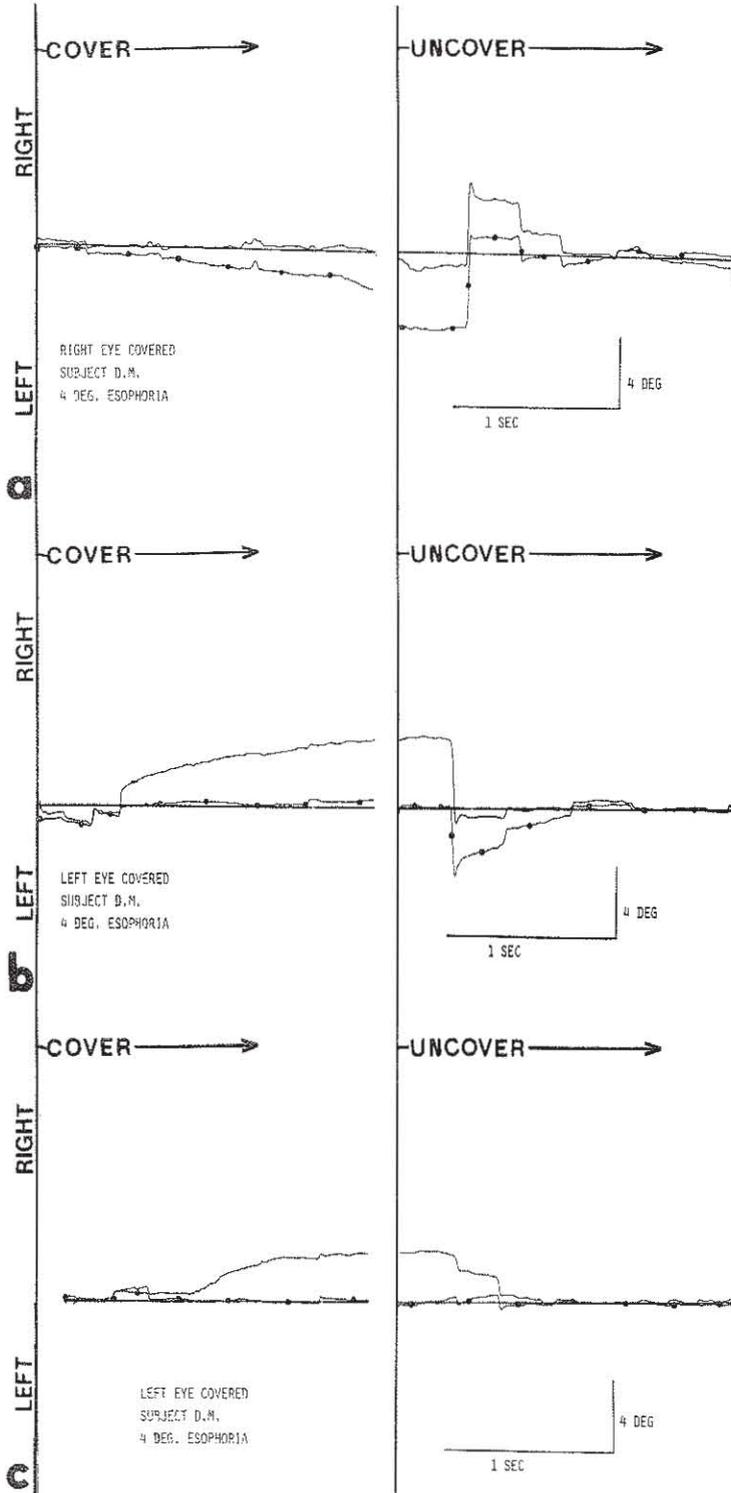


Fig. 6. Subject DM, a 4° esophore, presents bidirectional multiple saccades that are unequal and have clear overshoots on the uncover phase (a and b). Note that the disjunctive response of DM after right eye uncovering (a) is mediated predominantly within the unequal saccades while the smooth vergence response is minimal. During a few preliminary tests the saccades were unidirectional, i.e., towards the fixation point (c).

Large dynamic overshoots of uncover phase saccades were the most notable feature of cover test eye movements in two of our three esophores. These overshoots are seen less prominently in exophores MS (Fig. 1) and GM (Fig. 4), and hardly at all in the other five subjects. The magnitude of these overshoots appears to be closely related to saccadic amplitude inequality. Subject JB manifested both the largest overshoots of any of our subjects, and also the greatest degree of saccadic inequality. In Fig. 5, the saccadic amplitude inequality reduced the initial disparity demand by 60% when his right eye was uncovered, and by 80% when his left eye was uncovered. Subject DM illustrates the possibility that learning may influence the uncover phase response strategy (Fig. 6). The first three trials with the left eye covered showed repeated rightward saccades with little saccadic amplitude inequality and most of the disjunctive load falling on the vergence system (Fig. 6c). An additional 20 trials with the left eye (Fig. 6a) and right eye (Fig. 6b) showed oppositely directed (bidirectional) successive saccades within each response. The first of these bidirectional saccades features major dynamic overshoots and saccadic amplitude inequality which reduces the vergence demand. All three subjects (MS, DM, and JB) showing large dynamic overshoots had received some orthoptic training which relieved symptoms related to their heterophorias.

DISCUSSION

Irrelevant saccadic movements of the fixating eye were found in almost all records. The early-onset saccades were clearly unequal in the two eyes. Several explanations have been proposed to account for comparable inequalities of the right and left eye components of conjugate saccades in other asymmetric vergence studies. Ono and Nakamizo⁴ examined the hypothesis that exophoria might account for saccadic inequality in asymmetric vergence but dismissed this possibility after observing, as we did, that it was always the nonaligned eye which generated the larger saccade, regardless of the subject's heterophoria. Some amplitude inequality can be explained by assuming that vergence and saccadic movements sum linearly. According to this hypothesis, a saccade moving with the vergence would appear larger than a saccade moving against the vergence. Ono et al.¹³ have shown that this hypothesis cannot completely explain unequal saccades in asymmetric vergence as the magnitude and velocity differences between the eyes are too great to be explained on the basis of linear summation. Kenyon et al.¹⁵ also observed that asymmetric vergence saccades are smaller when driven against the vergence than

when moving with the vergence and that the magnitude of the inequality cannot be explained by linear summation of vergence and saccade. They proposed a model, based on the nonlinear force/velocity characteristics of the extraocular muscles, which accounted for the inequality of saccades during vergence eye movements, including the lessening of the inequality as saccadic latency increased. This model assumed that linearly summed Hering's law vergence and versional signals were sent to the extraocular muscles. Thus, unequal saccades associated with vergence do not necessarily violate Hering's law of equal innervation.

The significance of unequal saccades is that they contribute to the disjunctive response to a disparate demand. Both Kenyon et al.¹⁵ and we have shown that it is the eye moving with the vergence that manifests the larger saccade and it is that same eye which must make a larger movement in order to achieve bifixation on the point of regard. This disjunctive movement takes place during the short duration of a saccade and therefore changes the vergence posture of the eyes faster than the slow vergence response associated with it. We have shown, in two subjects, that this eye movement pattern does decrease the time required to complete a disjunctive response. This eye movement pattern might be appropriately termed "saccadic vergence."

The argument above suggests that the binocular system may be able to attain a larger as well as faster disjunctive response by the use of saccadic vergence combined with slow vergence than by the use of slow vergence alone. Because the model of Kenyon et al. implies that the saccadic inequality should be a fixed percentage of the average saccadic magnitude of a conjugate movement, then an observer could increase the absolute magnitude of his saccadic vergence by increasing the amplitude of the saccade. Moreover, if more than one saccade could be generated during the vergence, a subject could further reduce his disjunctive demand with saccadic vergence. Indeed, some of our subjects (DM and JB) conformed to these predictions by using dynamic overshoots and bidirectional saccades. It appears that the binocular motor system may in some cases use saccadic vergence to supplement smooth vergence velocity and amplitude.

The enhancement of saccadic vergence by dynamic overshoots can be explained on the basis of known mechanisms of saccadic eye movement control. Normal saccadic eye movements result from two innervational components: a low level "step" signal, which represents that innervation required to hold the eye at the destination target rather than the source target, and a high level "pulse" component, which maximizes the veloc-

ity of the saccade. This pulse component is composed of a sudden onset and offset of innervation with a programmed time interval between onset and offset. Bahill et al.¹⁷ have shown that dynamic overshoots result from two back-to-back oppositely directed pulse components which precede the step component. The contribution of the dynamic overshoot to saccadic vergence is twofold: (1) because saccadic vergence magnitude is proportional to the average saccadic amplitude of a conjugate saccade, then the initially larger amplitude of the overshoot saccade will result in a larger absolute disjunctive response than the same saccade without an overshoot, and (2) the return phase of the overshoot, being effectively another saccade, will produce its own saccadic vergence, further reducing the disjunctive demand.

A learning factor may contribute to the appearance of dynamic overshoots as all three subjects who manifested dynamic overshoots were trained observers who had undergone some form of orthoptics, and the other six were not so trained. Perhaps the double pulse sequencing of the saccadic pulse phase is subject to manipulation, and normal subjects can learn to use this sequencing to generate overshoot saccades which enhance saccadic vergence. It is also plausible that these saccadic overshoots are an inherent and unlearned characteristic of oculomotor innervation in those subjects with symptom-producing deficiencies of nonsquint binocular motor function. The appearance of overshoot saccades only in the later cover test trials of subject DM does not support this suggestion. We have also found in preliminary trials on one of us (GM) that larger saccadic overshoots can be voluntarily generated after a short number of cover test trials. We are currently testing the learning hypothesis in our laboratory by means of a longitudinal study of asymmetrical vergence movements in orthoptic patients and normals.

Pickwell⁹ observed that the irrelevant movement of the uncover phase was larger when the dominant eye was uncovered than when the nondominant eye was uncovered, and claimed that this difference was due to the ocular dominance. Ono and Nakamizo,⁴ using a disparity-only paradigm, tested Pickwell's hypothesis, but claimed that irrelevant saccade amplitude was associated with a subject-dependent preference for rightward or leftward saccades rather than ocular dominance. Our data seem to support Pickwell's dominance hypothesis because of the clear association of short-latency large-amplitude saccades with eye dominance. Long-latency saccades were frequent when uncovering the nondominant eye and were smaller in amplitude. The larger saccades exhibited by the uncovered dominant eye appear to result from the shorter

saccadic latency of the dominant eye. However, with our paradigm we cannot reject Ono and Nakamizo's explanation because heterophores respond in only one direction for each eye during the cover test.

As expected, irrelevant Hering-type movements of the fixating eye were found in most cover phase records. The saccades commonly found in our cover phase movements appear to perform a refoveation function after a slow drift away from fixation as do saccades in the Johannes Mueller experiment. Thus, there is a qualitative similarity of our cover phase results to those of Ono and Nakamizo⁴ in the Johannes Mueller experiment. Indeed, the conditions of the cover phase test and the Johannes Mueller experiment are quite similar except for the constancy of occlusion and the faster dynamics of the vergence response in the latter.

The results of the cover phase experiment seem to answer a question posed by Ono and Tam⁶ "(b) is asymmetric vergence due to addition of accommodative vergence (assumed to be asymmetrical by Ono and Tam) and fusional vergence or is it due to the addition of pursuit movement and fusional vergence?" Because our stimulus conditions would tend to suppress any significant accommodative vergence, then only a smooth pursuit could be combining with fusional vergence to produce the asymmetrical vergences observed here. The stimulus for these pursuit eye movements is probably an egocentric perceived movement of the point of regard accompanying the cover phase vergence. A moving target is not always necessary for the initiation of a smooth pursuit movement as the perception of movement has been shown to be a sufficient stimulus.¹⁸ Indeed, some exophoric subjects reported smooth movement of the target in the direction of the covered eye. This direction of apparent movement is the same direction required to drive a smooth pursuit eye movement which will result in asymmetric vergence when added to the divergence. This same rationale may explain asymmetric vergence found in uncover phase responses. Thus, asymmetric vergences, like unequal saccades, do not necessarily violate Hering's law of equal innervation.

Despite the universal acceptance and use of the cover test in oculomotor diagnosis, it has been used largely to determine the position of the eyes at rest, not to monitor the movements of the eyes. Perhaps this is due to the lack of a clinically useful data base and an appropriate technology. Advances in electro-optical and computer technology may soon make it possible to apply the type of methods we have used in the clinic. Our result that cover test eye movements follow the same rule (i.e., Hering's law) as other asymmetric vergence eye movements in

normal binocular vision eliminates the need for a separate data base for cover test eye movements. However, the significant differences in the responses of the two eyes, especially for subjects with clear ocular dominance, warrant further investigation. Furthermore, if a systematic investigation verifies our suggestion that the generation of unequal saccades with dynamic overshoots can be learned, then the objectively recorded cover test may prove useful as a diagnostic and therapeutic monitoring tool in the clinic.

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