evaluation of fixation disparity.
movements. J Physiol 1961;
ity. Abstract. Am J Optom Physiol
.ring convergence and divergence.
on upon fixation disparity. Vision
vergence eye movements and fix-
.359–67.
. Am J Optom 1980a;57(9):618–31.
nce eye movements: symposium
1–96.
odative vergence disorders of bi-
1982a;58: in press.
cts. In: Lennerstraud, G, ed. Func-
tockholm: Pergamon Press, 1982b.
rism adaptation, convergence ac-
rgence. Am J Optom Physiol Opt
ties of Panum's fusional area. Vi-
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sional components of fixation dis-
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lomotor imbalance. Am J Optom
ms with measures of oculomotor
978;55(10):670–76.
lateral fusional movements of the
rsity, Columbus, 1951.
inoscopy. Trans Am Acad Optom,
and experimental psychology.
its on the basis of fixation disparity.
4;31:624–35.
sustained improvement after short
Opt 1979;56(1):23–33.
Rev of Optom 1980;7:60–70.
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Validity of Diagnostic Criteria and Case Analysis in Binocular Vision Disorders

James E. Sheedy
J. James Saladin

The innervational pattern to the oculomotor system must be in balance so that a person can comfortably maintain bifixation of the object of regard. Individuals with an oculomotor imbalance may be able to maintain binocular vision, but do so with asthenopia, headache, blur, and/or intermittent diplopia. Asthenopia may be so severe after a prolonged visually intensive task that some avoid the task even when it is central to their occupations. The cost of oculomotor imbalances to the schoolchild may be even greater in that discomfort during near work (especially reading) may have long-term effects on educational development, career selection, and attitude. This chapter discusses the methods and criteria that are being used in differential diagnosis of horizontal oculomotor imbalances and suggests techniques that offer the promise of even greater diagnostic power.

PHORIA AND VERGENCE ANALYSIS

Clinical Measurement

The usual method of diagnosing horizontal oculomotor imbalances requires measuring heterophoria and vergence ranges, and takes into consideration the vergence demand point at several different fixation distances. Heterophoria is a tendency for deviation of the lines of sight from bifixation of the object of regard when fusion is eliminated. As such, it represents a rest position. It is commonly measured with the Von Graefe or Maddox rod subjective methods supplemented with the objective cover test. The magnitude of heterophoria varies with fixation distance (and therefore accommodative demand) if the AC/A ratio is not numerically equal to the patient's interpupillary distance. The amount of the heterophoria determines the fusional vergence needed to obtain bifixation. If either base-in or base-out prism is introduced under fused conditions, a negative or positive fusional vergence movement, respectively, must occur to reobtain the requisite alignment for fusion. As explained in Chapter 13 on Graphical Analysis, positive relative vergence is measured as the amount of base-out prism employed until a blur is noticed. Prism added until fusion is broken measures the positive and negative fusional vergences. It is common clinical practice for the prism amount to be reduced after diplopia is reported until the patient observes that the two diplopic images have become one. These three measurements are referred to as the blur, break, and recovery findings of the vergence measurement.

If the accommodative level is held fairly constant, the heterophoria measurement is easily repeatable within two or three prism diopters depending on the measuring method. Variability in the vergence amplitude measurements is greater. A difference of 10 prism diopters from one fusional vergence amplitude measurement to another is not unusual unless rigorous controls are applied. Not only do vergence ranges vary with the measurement method (prism bar or Risley prism), they also vary with the size and strength of the fusion stimulus, the attentiveness of the patient, the speed of prism change, and the immediate past history of vergence stimulation. With this variability in mind, one immediately sees that any criterion dependent on vergence ranges must be used according to some rather strict boundary conditions and instructions to the patient.

Normative Clinical Data

While the reader is referred to Borish (1970) and Chapter 13 for a complete description of the methods used for obtaining clinical data, a brief discussion of these methods is presented here with comments on analytical criteria. The methods can be divided into two general camps: those based on normative or expected values (an intersubject comparison), and those that compare various test results from a single patient (an intrasubject comparison). Examples of the first group include that proposed by Morgan (1944) and to a certain extent, the optometric extension program (OEP) analysis system (Lesser, 1974). Morgan's data are developed from the averages of over 800 prepresbyopic patients. The OEP table of expecteds was developed "by averaging the values found in thousands of cases" and a standardization process "from the clinical experience of practitioners" (Lesser, 1969). Morgan's and OEP data are presented in Table 15.1 together with similar data from Saladin and Sheedy (1979) that are based on a sample from a nonclinical population. Data from the three sources have a striking similarity considering the differences in construction of the studies. Saladin and Sheedy used conditions for heterophoria and vergence measurements, which were a compromise between those of Morgan (1944) and Sheard (1930). Measurements were made with the refractive correction in a phoropter, and the subject viewed a single column of 20/30 acuity letters. The heterophoria measurement was obtained by putting a 6^{Δ} vertical prism in front of one eye to obtain dissociation. The two images were aligned in the subject's visual space by varying a lateral Risley prism. Accommodative level was controlled by reminding the subject to keep the target clear, and one of the targets was flashed to minimize any subtle fusional effects. The vergences were measured by adding lateral prism slowly and equally to both eyes. Base-in vergences were measured before base-out. The amount of prism was recorded when the first sustained blur was detected (blur), and also when diplopia (break)

TABLE 15.1 Expected Values from OEP and Morgan Tables and Saladin-Sheedy Data

6 m	*OEP*	*Morgan*	*Saladin-Sheedy*
Phoria	0.5 exophoria	1 exophoria (2)	1 exophoria (3.5)
Positive vergences			
Blur	8	9 (4)	15 (7)
Break	19	19 (8)	28 (10)
Recovery	10	10 (4)	20 (11)
Negative vergences			
Break	9	7 (3)	8 (3)
Recovery	5	4 (2)	5 (3)
40 m			
Phoria	6 exophoria	3 exophoria (5)	0.5 exophoria (6)
Positive vergences			
Blur	15	17 (5)	22 (8)
Break	21	21 (6)	30 (12)
Recovery	15	11 (7)	23 (11)
Negative vergences			
Blur	14	13 (4)	14 (6)
Break	22	21 (4)	19 (7)
Recovery	18	13 (5)	13 (6)

Numbers in parentheses = standard deviation values.
All values are in prism diopters.

was noticed. The prism was slowly reduced until fusion (recovery) occurred with the subject trying to regain fusion.

Differences between Morgan's values and those of Saladin and Sheedy illustrate the difficulty in determining population norms. For example, Morgan's were mainly from a prepresbyopic clinical population. Saladin and Sheedy's were from a nonclinical, young adult (ages 20 to 30 years) population. Note the significant difference in positive vergence ranges. Ignoring any age differences, it would seem that a clinical population has smaller positive vergence ranges than does a nonclinical population. From which group is the positive vergence criterion to be chosen? Assuming that there is a relation between the positive relative vergence value and binocular efficiency and/or comfort, even the averages of a nonclinical (and visually healthy) population may not yield the best criterion value. Morgan's expecteds are always given with a range value, which, when taken into consideration, partly compensates for the difficulty just mentioned. Morgan provided a further compensation for this difficulty when he grouped the various clinical parameters that were best correlated with others in the group. For example, his group A consisted of negative relative vergence at distance, negative relative convergence and fusional reserve at near, positive relative accommodation, and amplitude of accommodation (Morgan, 1964). According to graphical analysis, this would be the top and the left (base-in) side of the zone. If all components of the group varied from an expected value in an appropriate direction, a reliable diagnosis could be made. Therefore Morgan's actual diagnostic criterion was not simply a series of numbers as listed in his Table of Expecteds, but a necessary agreement among subcriteria of correlated clinical parameters.

Clinical Analysis of Normative Data

From these concepts, several problems can be seen to develop when normative data gathered from a population are applied to a particular individual and used as criteria or indicators:

1. Population averages may not be the optimum value. As Morgan (1964) put it, "Averages tend to tell what a population is rather than telling what it should be."
2. There are differences in the averages for subpopulations. How many differences exist and how do we determine the subpopulations?
3. Some clinical data, particularly vergence ranges, have poor reliability even though the examiner uses the same conditions and patient instructions on which averages are based.

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Analyses of graphically represented data provide the foremost examples of analytical systems that use criteria based on intrasubject data. Classical methods do not provide criteria for as many clinical parameters as do the OEP and Morgan's normative systems; therefore graphical analysis cannot be used as a complete substitute for either. Percival and Sheard give examples of classical criteria used in graphical analysis that depend on an intrasubject data comparison. Percival's (1928) is applied by measuring the positive and negative relative vergences, adding their absolute values, and determining the middle one-third of this vergence range. According to Percival, binocular comfort is to be expected when the demand point falls anywhere within this area or "zone of comfort."

Sheard's criterion (1930) can be stated as a requirement that the fusional reserve amount be twice the amount of the fusional demand. The fusional reserve is the relative vergence in the opposite direction from the heterophoria, and the fusional demand is the amount of heterophoria. For instance, a 6^{Δ} exophore should have at least 12^{Δ} of positive relative vergence at that fixation distance. The criterion was to be applied at several fixation distances. In actual practice, the application of Sheard's and Percival's criteria provide about the same results if the phoria falls in the middle of the vergence range. In a sense, both are based on a population norm just as Morgan's system and that of the OEP. Percival determined statistically that the middle one-third of the vergence range was a zone of comfort and Sheard similarly relied on clinical experience to determine that a 2:1 reserve:demand ratio was adequate.

FIXATION DISPARITY CRITERIA

Clinical Measurement of Fixation Disparity

In recent years, fixation disparity has been used to diagnose imbalances of the oculomotor system. Its chief advantage over phoria-vergence analysis is that the oculomotor system is examined under binocular and, presumably, more natural conditions. Fixation disparity is a small misalignment of the eyes under fused conditions from an exact bifixation of similar images onto corresponding points. The misalignment is on the order of a few minutes of arc. Such a small error is tolerated without diplopia because of the existence of Panum's areas. If a horizontal fixation disparity exists, the eyes will be slightly overdiverged or overconverged for the object of regard. In Figure 15.1 the eyes are overdiverged, and the lines of sight meet behind the plane of regard.

Figure 15.2 illustrates the Disparometer, a clinical instrument designed for measuring fixation disparity at a 40-cm viewing distance. The

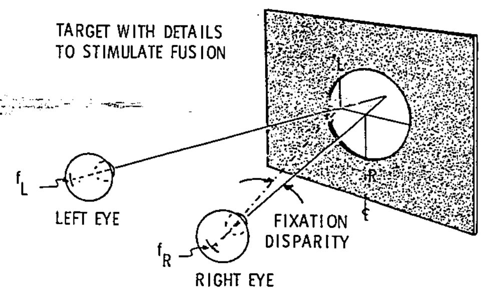

FIGURE 15.1. An illustration in perspective of an exofixation disparity. Note that the visual axes cross behind the plane of regard and that the nonius lines must have horizontal separation if they are to be imaged on the foveas. The fixation disparity angle is indicated by arrows. Adapted from Martens TG, Ogle KN. Observations in accommodative convergence, especially its nonlinear relationships. American Journal of Ophthamology, 1959. Reprinted by permission of the publisher.

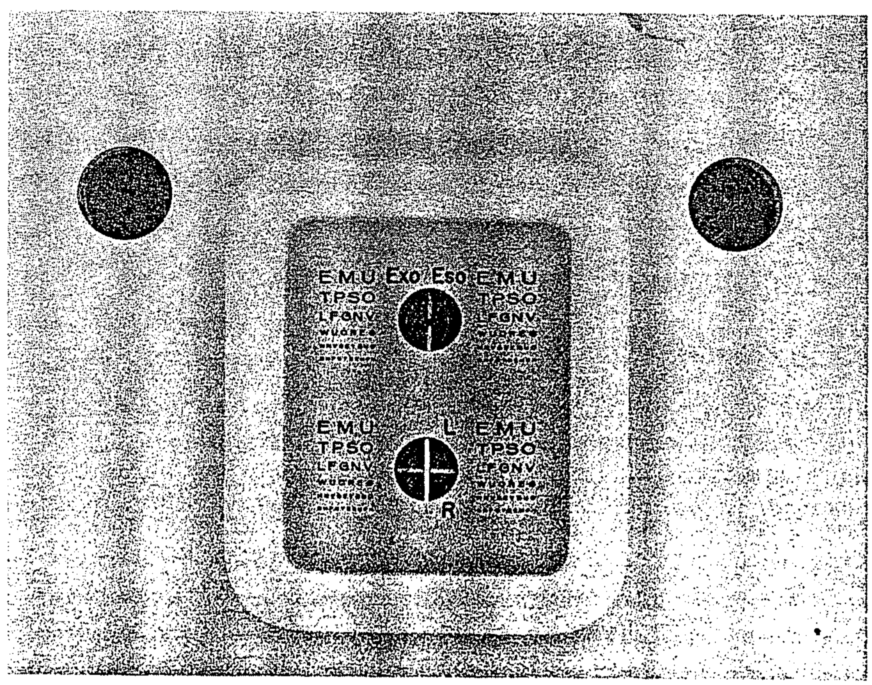

FIGURE 15.2. The Disparometer instrument for measuring fixation disparity at near distances. The subject is presented with different horizontal separations of the nonius lines until the two are seen vertically aligned. The fixation disparity amount can be read from a dial on the back. Note the small Snellen charts for use in stabilizing accommodation. (Vision Analysis, Box 14390, Columbus, OH 43214)

instrument has two binocularly seen circles, each of which subtends an angle of 1.5°. The upper stimulus is used to measure horizontal fixation disparity and the lower to measure vertical fixation disparity. Only horizontal fixation disparity is discussed here. Because nothing within the confines of the circle is seen by both eyes, the circle is the primary stimulus for fusion. The upper half of the circle is perpendicularly polarized with respect to the lower half. Each half-circle contains a polarized vertical line that can be seen by only one eye of the patient. Lateral misalignment of the two vertical lines is controlled by the examiner. If the vertical lines are aligned in real space but are seen as misaligned, a fixation disparity exists. Although the binocular system is using Panum's areas to maintain fusion, the oculocentric direction of each eye remains to be computed from the fovea. To measure the amount of fixation disparity, the lines are adjusted until the subject reports alignment in visual space. The physical horizontal misalignment that the two vertical lines subtend at the viewing distance is the angular measurement of fixation disparity. A horizontal midline through the circle is sometimes used to provide a vertical fusion lock. Accommodation is stabilized by instructing the patient to keep the visual acuity chart letters at the sides of the circle as clear as possible while the setting is being made.

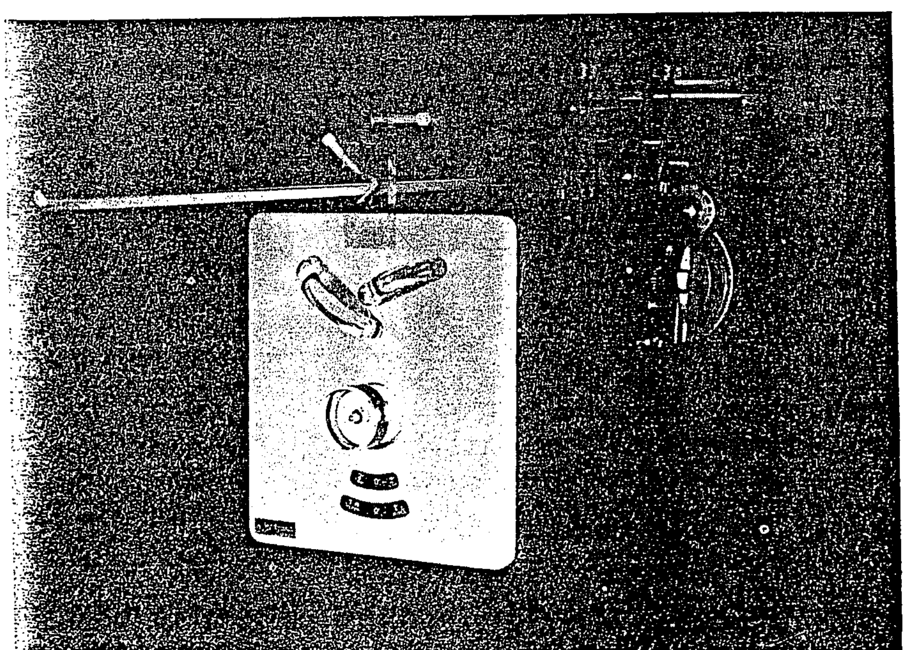

FIGURE 15.2. (Continued)

For a given accommodative stimulus level, the amount of fixation disparity can be manipulated by forcing vergence through the use of prisms. Figure 15.3 is a graphical representation of the relationship. On the horizontal axis the amount and base direction of the prism introduced before the eyes is indicated. Base-in is indicated to the left and base-out to the right. The corresponding fixation disparity angle is indicated on the vertical axis with esofixation (overconverged) disparity above the origin. Prism diopters are plotted on the horizontal axis and minutes of arc on the vertical axis. As indicated in the figure, base-out prism usually causes a relative exofixation disparity and base-in prism a relative eso-fixation disparity.

Analysis of Fixation Disparity Data

There are four descriptive characteristics of a fixation disparity curve (FDC) as shown in Figures 15.3 and 15.4. The first is curve type (shown in Figure 15.4). The second is the vertical axis intercept (Y intercept), which is a measure of the angular amount of fixation disparity with no induced prism stress. The third is the horizontal axis intercept (X intercept), which is the amount of prism needed to neutralize the fixation disparity to zero (associated phoria). The fourth point of interest is the

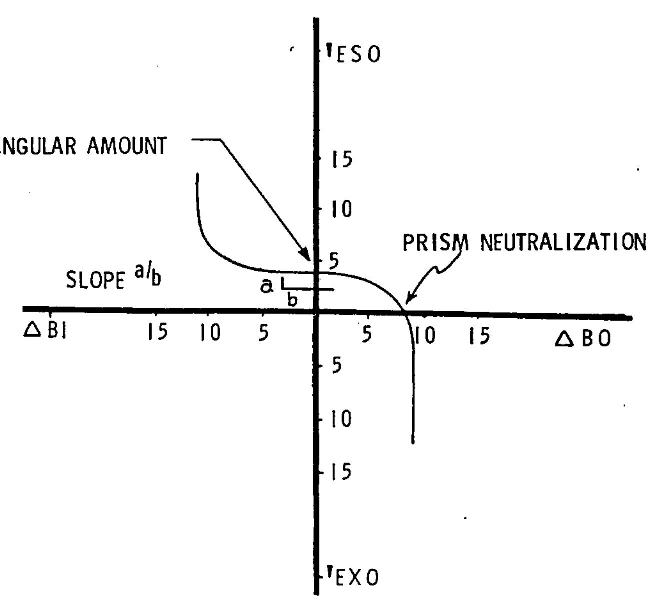

FIGURE 15.3. Slope, angular amount of fixation disparity, and amount of prism needed for neutralization of the fixation disparity are indicated.

slope of the curve as it crosses the vertical axis. Each characteristic could be used in the formulation of a criterion.

Ogle, Martens, and Dyer (1967) classified the curves according to shape. While this classification is not the only one and has some limitations, it is certainly the most widely referred to and is used in this chapter. The four curves are illustrated in the four sections of Figure 15.4. The most common (type I) is sigmoid-shaped and has a tendency for verticality on both ends. Type II curves lack the downward portion of the curve on the base-out side and type III lack the upward portion on the base-in side. A type IV curve is a sigmoid terminating in horizontal lines. The relative frequency of the curve types is given in Table 15.2 in which Saladin and Sheedy's (1979) data are compared to Ogle's. Type I curves are most frequent, followed by type II, type III, and type IV in that order. The differences among the data in the table are most likely due to the populations from which the samples were drawn. While Ogle, Martens, and Dyer (1967) reported that curve type can change with fixation distance, this conclusion needs to be verified. Additional studies are also needed on the effect of strength and size of fusion contours, accommodative state, and orthoptics on curve type.

The most widely used descriptive characteristic of fixation disparity is the horizontal axis intercept, which indicates prism amplitude that will neutralize fixation disparity. Ogle and associates (1967) called this point the associated phoria to distinguish it from the dissociated phoria described previously. The associated phoria is determined clinically with a Mallett unit (Mallett, 1964, 1966), Borish card (Borish, 1978), AO Vectograph, or Disparometer (Sheedy, 1980a). A successful variation of this neutralization technique based on Carter's (1965) work prescribes the least amount of prism that will neutralize fixation disparity for a 10-minute period. Excellent results have been obtained with this technique for correcting both vertical and horizontal imbalances. Carter maintains that if the fixation disparity cannot be neutralized with this technique,

TABLE 15.2 Relative Frequency of Curve Types

	Distance		*Near*	
Type	*Ogle, 1967* (%)	*Saladin and Sheedy, 1979* (%)	*Ogle, 1967* (%)	*Saladin and Sheedy, 1979* (%)
I	57.5	68.3	57.2	58.2
II	30.0	26.7	22.1	27.6
III	9.0	0	13.4	8.2
IV	3.4	5.0	4.9	7.2

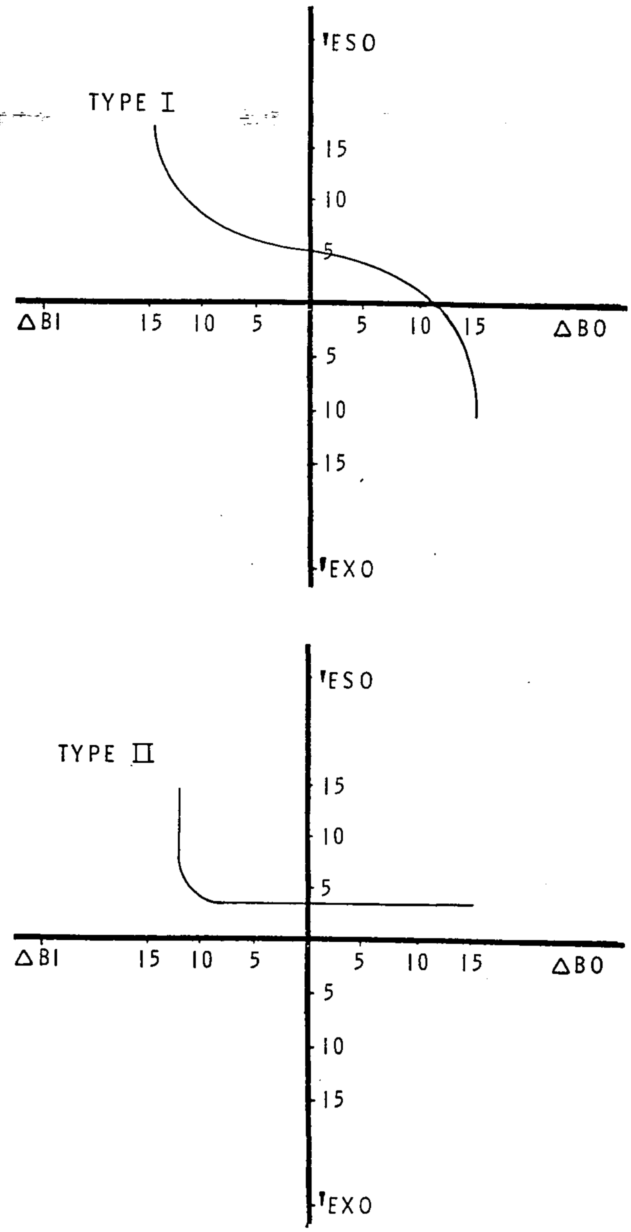

FIGURE 15.4. The four types of fixation disparity curves as described by Ogle et al., 1967. A Type I. B Type II. C Type III. D Type IV.

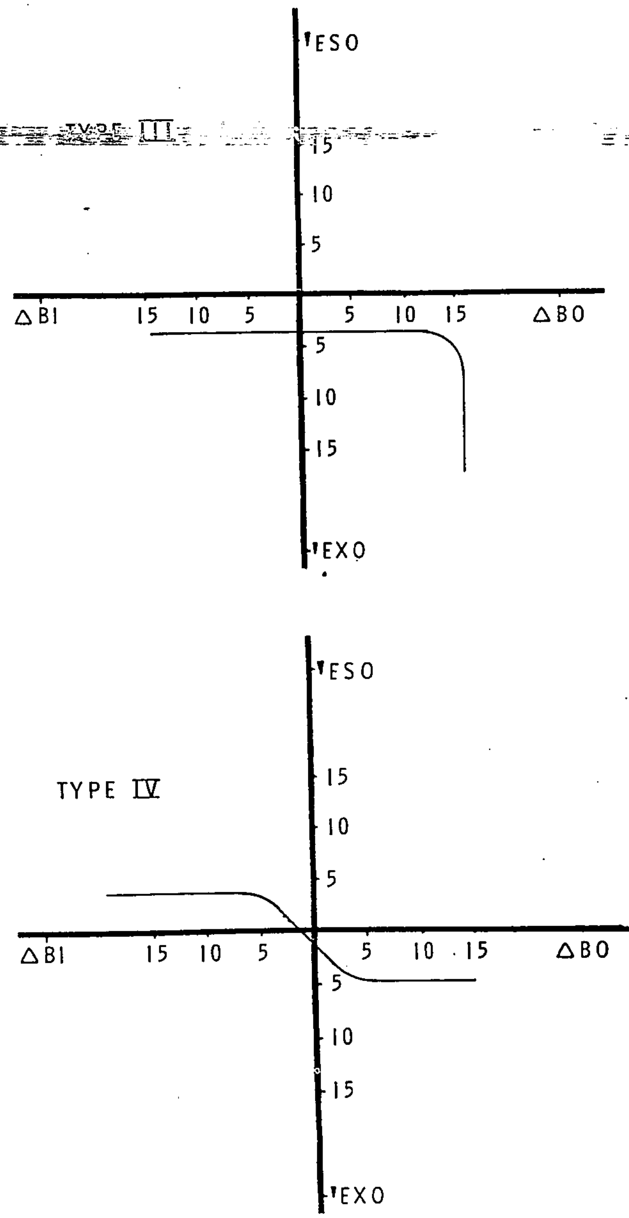

FIGURE 15.4. (Continued)

the patient's particular binocular system is very adaptable and probably will not profit by a prism prescription.

The Y axis intercept, or the angular amount of fixation disparity with no additional prism, shows promise of being of diagnostic use but its magnitude is more susceptible to variation than is the associated phoria. This leads to complication in its clinical application. For instance, the angular amount of fixation disparity is strongly dependent on the strength and size of the fusion contour. The greater the distance between the fusion contour and the fixation point, the greater will be the amount of fixation disparity. This relationship between size of fusion contour and the X axis intercept does not hold, however. Ogle and co-workers (1967) showed that as the fusion contour size increased the fixation disparity curve rotated about the X axis intercept. While there is some disagreement, it is our experience that this tentative conclusion is correct. Because of the stability of the X axis intercept, many practitioners who use the prism-to-neutralization method prefer to use a fixation disparity device without a central fusion lock. The prism needed for neutralization

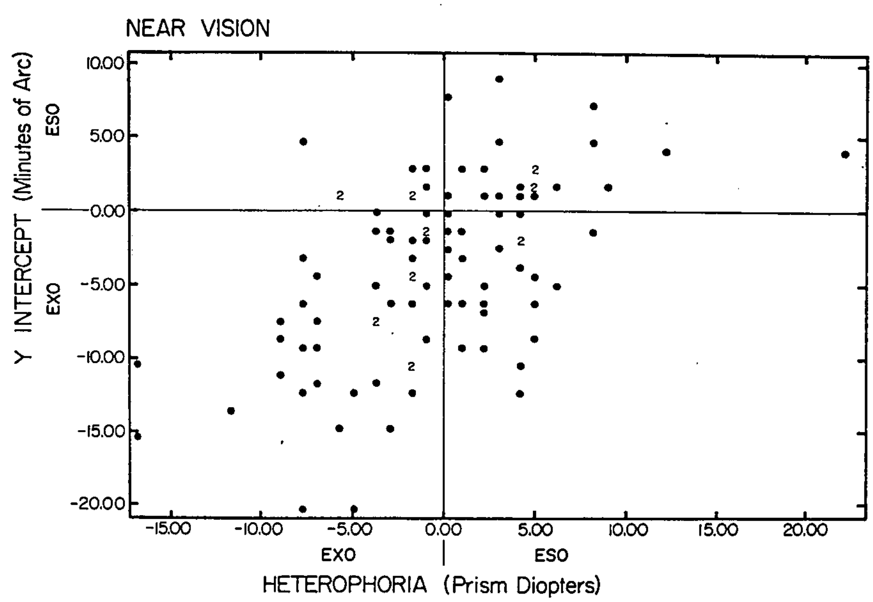

FIGURE 15.5. The amount and direction of heterophoria is plotted against the corresponding amount and direction of fixation disparity. Some 25% of the data points fall in quadrants 2 and 4, showing either esophoria with exofixation disparity or the reverse. These data were taken at a near (40 cm) testing distance. Reprinted by permission of the publisher, from Saladin JJ, Sheedy JE. Population study of fixation disparity, heterophoria, and vergence. American Journal of Optometry and Physiological Optics, 1978.

is the same with and without the central fusion lock, however, the patient's task is made easier by a greater apparent deviation of the two polarized nonius lines when they are absent.

The fourth point of interest on the fixation disparity curve is the slope (Figure 15.[illegible]). The steeper the slope, the less the binocular system is able to adapt to prism-induced stress without changing fixation disparity. We have defined the point on the horizontal axis indicating the habitual prism prescription (usually the origin) as the operating point. It is the slope of the curve at the operating point that may be of diagnostic importance. Variables that have an effect on slope include size and strength of fusion contour. The slope has a tendency to increase as the size of fusion contour grows and as its strength is lessened. The fusion contour can be strengthened by increasing contrast, sharpening borders, and to a certain extent, increasing the number of contours.

Relationship of Fixation Disparity and Phoria-Vergence

How closely related is the phoria-vergence relationship to fixation disparity? (See Figures 15.5 and 15.6.) If fixation disparity were due to the

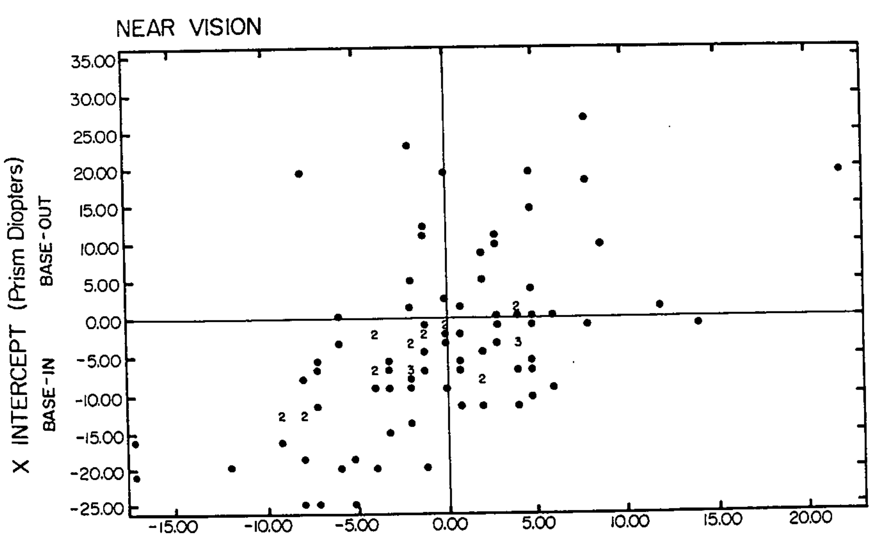

FIGURE 15.6. The amount and direction of heterophoria is plotted against the corresponding amount and direction of prism needed for neutralization of the fixation disparity. As in Figure 15.5, some 25% of the data points fall in quadrants 2 and 4. Reprinted by permission of the publisher, from Saladin JJ, Sheedy JE. Population study of fixation disparity, heterophoria, and vergence. American Journal of Optometry and Physiological Optics, 1978.

binocular system applying only a comfortable minimum of fusional vergence to overcome the phoria, one would expect that exophores would have an exofixation disparity and esophores an esofixation disparity. Figure 15.5 from Saladin and Sheedy (1979) shows that this is not true in at least 25% of the cases. One would also expect that an exophore would require base-in prism to more fully overcome the exofixation disparity and similarly, esophores would require base-out prism. Figure 15.6 shows that this is far from a general statement of truth. The explanation for fixation disparity must include more than the idea that it is a slight misalignment to conserve the neural effort involved in overcoming the heterophoria. A direct relationship between fixation disparity and phoria cannot be expected. As described in Chapter 14, fixation disparity is measured under binocular conditions, with an interchange occurring among accommodative convergence, convergence accommodation, and fusional vergence. A dissociated phoria measurement is made under nonfused conditions with binocular factors providing only a residual tonic effect. Fixation disparity and the phoria should be regarded as two somewhat dependent variables, but sufficiently independent to warrant both of their measurements for diagnosing horizontal oculomotor imbalances.

RELATIONSHIPS OF DIAGNOSTIC CRITERIA TO ASTHENOPIA

Symptoms

The most common manifestation of an oculomotor imbalance is asthenopia. The individual will complain of eye fatigue, intermittent diplopia, headaches, and/or inability to perform necessary visual tasks for an extended period of time. Symptoms will be associated with use of the eyes at the distance where the imbalance occurs; most frequently this is at the near working distance. The extent of symptoms will depend on both the severity of imbalance and on the individual's visual workload. Since elimination of symptoms is the goal of therapy, presence or absence of asthenopia has often been used as a criterion for evaluating the various clinical measures.

Arner and Colleagues Study

Arner and colleagues (1956) obtained an asthenopia measure on a group of 35 subjects by way of questionnaire and interview. They also measured the phoria, vergences, and fixation disparity curve (FDC) at a 2.5-meter test distance. The ordering of subjects according to degree of asthenopia was best correlated with the FDCs, which were ranked on the basis of (1) total length of curve, (2) slope of curve, (3) low amount of fixation disparity, and (4) symmetry of the curve around the point of demand. There was not a significant correlation between asthenopia ranking and rankings based on either Percival's or Sheard's criterion.

Sheedy and Saladin—First Study

Sheedy and Saladin (1977, 1978) studied the relationship between asthenopia and various clinical measures of oculomotor balance in two separate studies. In the first, 32 students were selected from a group of 50 on the basis of questionnaires and interviews to serve as an asymptomatic population; 28 patients from the orthoptics clinic at the Ohio State University were the symptomatic population. These patients had been referred to the clinic on the basis of an initial vision examination at which the diagnosis indicated an oculomotor imbalance with associated symptoms. Phorias, vergences, and FDC were measured on all 60 subjects.

Stepwise discriminant analysis (Klecka, 1975) was used to select the clinical test results (variables) that best indicated or predicted the proper segregation of the population into symptomatic and asymptomatic groups. The variables chosen were the phoria; blur, break, and recovery ranges; Percival's criterion; Sheard's criterion; vergence opposite the phoria; X intercept; Y intercept; and the slope of the FDC around 0 (the operating point). Stepwise discriminant analysis selected the variables one at a time in the order of their discriminability. After each was selected, the remaining variables were completely reanalyzed to assess which one was most discriminative *after* the previously selected ones were taken into account. This is similar to the approach a clinician uses in diagnosing a case; first, looking to the test result that is the best indicator of a problem, then looking at the result that best identifies problems the first test missed.

Table 15.3 lists the variables in the order in which they were selected in the first study (Sheedy and Saladin, 1977). The statistical analysis was performed on the entire population of 60 and also individually on the exophoric ($n = 38$) and esophoric ($n = 19$) segments of the population. Sheard's criterion was the best variable for the entire population and for the exophoric subjects, but was not selected for the esophores. For esophoric subjects the amount of deviation (phoria) was most discriminating. In each of the three categories the second variable chosen was fixation disparity. The slope of the FDC was the next best for the entire population and for the esophoric subjects. A steep slope was associated with the symptomatic population. For the exophoric subjects the second variable chosen was the Y intercept.

TABLE 15.3. The Order in which Clinical Values were Discriminative between Symptomatic Patients and Asymptomatic Students

All Subjects	*Exophores*	*Esophores*
Sheard's amount	Sheard's amount	Phoria
FDC slope	Y intercept	FDC slope
Vergence opposing phoria	X intercept	Recovery range
Recovery range	Vergence opposing phoria	Break range
Break range	Vergence recovery	Vergence opposing phoria
90% correct	89% correct	89% correct

Source: Sheedy and Saladin, 1977.

Sheedy and Saladin—Second Study

A second study (Sheedy and Saladin, 1978) was performed to substantiate the findings of the first and to institute additional experimental controls. A total of 103 optometry students served as subjects. A questionnaire evaluated frequency and severity of symptoms. Symptoms for known reasons other than oculomotor imbalance (e.g., contact lenses, allergies, etc.) were eliminated, creating an asymptomatic group of 44 and a symptomatic group of 33. This manner of obtaining the two populations, that is derived from a single homogeneous population, offered the advantage that the groups were not separated or selected on the basis of any previous analysis of clinical data. In the first study the symptomatic group was referred on the basis of an analysis of variables that were later statistically tested for discriminability. Also, at the time of referral, only phoria-vergence data were available, which would favor selection of those variables over FDC variables. The selection method in the second study is also advantageous since it resulted in symptomatic and asymptomatic groups that were similar in age and near vision workload requirements. A drawback, however, was that the severity of symptoms in the symptomatic group was not as great as in the first study, where symptoms were severe enough for subjects (patients) to seek professional care.

The variables used in the second study for stepwise discriminant analysis were slightly modified. Negative and positive blur, break, and recovery findings as well as the phoria were used. Sheard's and Percival's amounts were calculated based on the recovery and break findings as well as on the traditional blur findings. In addition to the FDC variables used in the first study, a variable that identified the type of FDC as type I or non-type I (II, III, or IV) was used. The results of the second study are presented in Table 15.4. Stepwise discriminant analysis was performed on the entire subject population, the exophoric and esophoric subpopulations, and the exofixation and esofixation disparity subpopulations.

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TABLE 15.4. The Order in which Clinical Values were Discriminative between Symptomatic and Asymptomatic Students Derived from the Original Population

All Subjects	Exophores	Esophores	Exofixation Disparity	Esofixation Disparity
Sheard blur	Y intercept	Percival break	Sheard blur	FDC slope
FDC type	FDC type	Positive blur	FDC type	Percival recovery
FDC slope	Negative break	Negative break	FDC slope	X intercept
Negative blur	Phoria	Percival recovery	Negative blur	Percival break
Y intercept	Percival blur	FDC slope		
Positive blur		X intercept		
Phoria				
82% correct	92% correct	73% correct	76% correct	96% correct

Source: Sheedy and Saladin, 1978.

The results for the entire population were very similar to those of the first study. Sheard's criterion (the traditional one based on blur value) was the best discriminator. The FDC type, which was not used in the first study, was the second variable chosen. The non-type I curves was associated with the symptomatic group. The slope of the FDC was chosen third, having been chosen second in the first study.

The variables chosen for the exophoric and exofixation disparity groups were different from one another. The first variables chosen for the exofixation disparity group were identical to those for the entire population. As in the first study, Sheard's criterion followed by fixation disparity variables was discriminative for exodeviations. For the exophoric group the Y intercept and FDC type were the most discriminative values and Sheard's criterion did not appear as a discriminator. Sheard's criterion by itself was discriminative for the exophoric population at the 1% level of significance; but the discrimination provided by the Y intercept and FDC type explains the discrimination of Sheard's criterion so that it was not selected. The FDC type offered the most discrimination after the Y intercept, indicating that the information provided by these two variables was not redundant.

As in the first study, Sheard's criterion was not selected for esodeviations. Percival's criterion was selected; however, it was based on the break or recovery findings, which were also discriminative. The traditional Percival's criterion (1928) based on the blur findings was not selected as a major discriminative value in either study. The FDC slope was the best discriminator for the esofixation disparity group.

The percentage of the total population that was properly identified as symptomatic or asymptomatic was not quite as high in the second study as in the first (82% vs 90%). This was due to the subject selection method, which resulted in less severe symptoms in the second study. It is remarkable, however, that such highly successful percentages were obtained for the exophoric and esofixation disparity groups. Fixation disparity variables were the best discriminators for symptomatic and asymptomatic groups.

CLINICAL DIAGNOSIS

The Problem

There is no single measure that can be used to assess the patency of the oculomotor system. It is important to understand which of the clinical measures are most effective indicators of abnormality and how they may be used to complement one another for diagnostic purposes. Correlations with asthenopia show that those based on both fixation disparity curve and phoria-vergences are useful and that a diagnosis is strengthened when both types of measurements are made because they assess different aspects of the oculomotor system. The FDC is a measure of fine alignment of the system during binocular fusion and its reactions to induced stress. It is strongly influenced by the sensory fusional system. The phoria and vergence measurements are indications of the gross alignment and neuromuscular abilities of the system and are influenced strongly by the motor fusional system.

Fixation Disparity

It appears that the FDC type identifies a basic characteristic of the system and is the most diagnostic FDC parameter. Type I curves are most often associated with a lack of symptoms and the other types (II, III, and IV) with symptoms. Not all type I curves are normal, however, nor are all other curve types abnormal; but curve type is a primary indicator, and analysis of an FDC best begins here.

The slope of the FDC is the next aspect of an FDC to assess. Its value depends on which portion of the FDC is specified. The portion that is most important is where the patient is "operating," that is, around 0^{Δ} for the patient who is not wearing prism. As indicated by Schor in Chapter 14, a flat slope is most desirable. The slope value that best discriminates between symptomatic and asymptomatic patients is -0.96 minutes per $^{\Delta}$, or approximately -1.0 minutes per $^{\Delta}$ (Sheedy and Saladin, 1977) using the stimulus parameters shown in Figure 15.2. If prism diopters and minutes of arc are graphed equally, a slope of greater than 45° is poor. The clinical rule of thumb is that the fixation disparity in minutes should change less than the prism in prism diopters. The slope is more diagnostic for the esodeviations. Also, the critical value of the slope is flatter for esophoria than exophoria (-0.77 minutes per $^{\Delta}$ compared to -1.06 minutes per $^{\Delta}$), indicating that esophoria is less tolerant of a steep slope than is exophoria.

The Y intercept was also diagnostic, but more so for exodeviations than esodeviations. For exophores the criterion value that best discriminated between symptomatic and asymptomatic patients was 12.1′ exofixation disparity (Sheedy and Saladin, 1977). For esophores it was 0.2′ exofixation disparity, with esofixation disparity associated with the symptomatic group. This was an indication that any amount of esofixation disparity measured with the Disparometer may be suspect. The most common values are low amounts (less than 10′) of exofixation disparity. The associated phoria (X intercept) was not as diagnostically significant as the other FDC variables.

Stability is another aspect of fixation disparity that should be evaluated. Nearly all patients note small movements of the vernier lines with respect to one another. They are caused by small disjunctive eye movements. For most patients these movements do not seriously interfere with the measurement of fixation disparity. When encouraged to be critical, that is, forced to choose on the disparity presentations, most patients can reliably identify the amount of fixation disparity to within two minutes of arc. Excessive movement of the two lines indicates excessive eye movements and instability in the accommodative mechanism. These factors interfere with the patient's ability to assess which disparity presentation appears aligned. The amplitude of movement may be as high as 10′ or more as measured by finding the disparity presentations that bracket the range.

Phoria and Vergence

Sheard's and Percival's criteria provide the best means to analyze the phoria and vergences. The former, which states that the opposing blur vergence amount should be twice the phoria amount, is a powerful diagnostic aid—but only for exophoria. Implicit in Sheard's criterion is the concept that the opposing vergence overcomes the phoria. Hence the positive vergences overcome an exophoria. The positive vergences are an active process whereas the negative vergences are more passive. Esophoria should be analyzed with a revised Percival's criterion, which is that the positive break should not be more than twice the negative break. Meeting this criterion ensures that the patient operates in the middle one-third of the vergence range. The phoria is not even a part of this criterion and the criterion does not imply that vergence overcomes an esodeviation.

CLINICAL TREATMENT

A binocular imbalance needs to be treated if there are symptoms associated with use of the eyes that might result in poor visual performance or avoidance of use of the eyes (especially at near). Options for treatment are prism, lenses, vision training, or combinations thereof. The specific treatment for a given imbalance will depend on factors other than measurements of the oculomotor system. Motivation of the patient (especially for training), whether a refractive correction or contact lenses are worn, the amount and critical nature of visual use (especially at near), the binocular status at distance when prescribing for near, adaptability of the patient to a prism prescription, and patient history can all influence treatment. Analysis of clinical measurements, as presented below, must be tempered with these factors when treatment decisions are made.

Vision Therapy

Increasing the positive vergences with vision training will often reduce the symptoms of an exophore who has failed Sheard's criterion. Prism prescriptions are less effective than convergence training for these patients (Worrell et al., 1971). Percival's criterion (using the break findings) is diagnostically significant for esophoric imbalances. To meet this criterion, the negative vergences in esophoria must be increased either with ophthalmic aids or with vision training. Esophores are often prescribed prisms and lenses on the basis of FDC analysis. Lens prescriptions are also calculated on the basis of the AC/A ratio. Vision training is more difficult for an esophore than for an exophore. The negative vergences, which are a passive process, are best improved by strengthening sensory fusion, which allows the eyes to maintain sensory fusion for greater divergence levels. Strict adherence to this criterion would dictate that improving the positive vergences would be detrimental to an esophore. Increasing positive vergence ranges are usually the result of developed adaptation abilities, which can also transfer to adaptation and extension of the divergence prism range (see Chapter 14).

The primary effect of orthoptic training is to flatten the slope of the FDC. The slope of a steep type I curve, which is often found in conjunction with exophoria that fails Sheard's criterion, can be reduced. Gross motor training is indicated and may be followed by fine motor training in the form of jump vergences to reduce the slope of the curve where the patient is operating. The Y intercept may or may not change as the result of training. The slope of type II FDCs typically will not change; prism and/or lenses are usually the treatment of choice. The slope of type III FDCs can be reduced, but they are more difficult to alter than the slope of type I curves. We have had some success in reducing symptoms of patients with type IV FDCs. The type IV curve usually indicates binocular abnormality and it requires extensive sensory and gross convergence and divergence training. Type IV curves do not lend themselves to slope analysis since they are usually flat, yet associated with symptoms.

In some cases the amount of fixation disparity is unstable and the patient will show accommodative fluctuations during dynamic retinoscopy. Instability of the fixation disparity is associated with fluctuations of accommodative convergence. The fixation disparity is usually exodisparity in these cases, since the accommodative lag is often large. Accommodative training and/or plus lenses are the therapy of choice.

Lenses and Prisms

When prescribing from an FDC the goal is to enable the patient to operate on a portion of the curve that is relatively flat, and where the amount of the fixation disparity is stable (Sheedy, 1980b). The portion of FDC intersecting the Y axis where the patient is operating may be changed by prescribing prism or lenses. A plus lens in the form of reading glasses or a bifocal is indicated when there is esofixation disparity at near, especially if there is asthenopia or poor near performance such as is commonly observed in school children. In our first clinical study (Sheedy and Saladin, 1977) any amount of esofixation disparity in an esophore was associated with the symptomatic population. A plus lens addition can reduce or eliminate the esofixation disparity at near as described in Chapter 14. In cases of accommodative instability, where the amplitude of accommodation is fluctuating, the amount of the fixation disparity will also be fluctuating. Very often in these cases a plus lens addition will stabilize the accommodation and the amount of the fixation disparity.

Prism prescription is primarily based on analysis of the slope of the FDC. Many patients who are operating on a steep portion of the curve will have a flatter portion elsewhere. Enough prism should be prescribed to enable operation just inside this portion. If there is no flat portion of the curve, training is indicated to reduce the slope. If training is not possible or successful, prism should be prescribed to reduce the amount of fixation disparity. In some cases there may be a slight inflection in the curve, which indicates a center of symmetry (Ogle et al., 1967) and this may be used for a prescription. Reversal of the habitual fixation disparity is contraindicated so that the prism prescription should normally not exceed the X intercept (associated phoria). Prescription of prism will sometimes drastically improve the stability of the fixation disparity measurement (Y intercept). Increased stability may be used as a criterion for the amount to be prescribed. Some patients with large exophorias (even intermittent exotropia) will show a paradoxical esofixation disparity. In these cases the base-out prism prescription based on the FDC has been found to provide relief of symptoms (Sheedy, 1980b). A plus lens addition may also be considered for near distances. The FDC may be used to assess the effectivenes of tentative prism and near add prescriptions. The effects of prism and lens adds on FDC are described in Chapter 14.

SUMMARY

Armed with the measurements of the phoria, vergences, and fixation disparity, the clinician must assess whether asthenopia can be ascribed to a binocular imbalance. A clinically useful diagnostic method should yield reliable (repeatable) information that will be a direct measure of the binocular balance of the visual system under examination. Furthermore, the results should be analyzed in terms of an acceptance or rejection criterion. Some flexibility is necessary, however, since just as there is no sharply definable level between an inefficient and an efficient binocular system, there is no sharply defined criterion.

For any given patient the various criteria discussed here may agree or disagree. Disagreement need not suggest that one criterion is wrong and another right, rather that only certain aspects of the oculomotor system are not optimal and that the two criteria are not totally redundant. As an example, in a controlled study (Sheedy and Saladin, 1975) fixation disparity amplitudes predicted the lack of symptoms observed in presbyopes who disobeyed with impunity the conventional Sheard-Percival criteria of proper balance between the phoria and opposing vergence amplitudes. The lack of symptoms was explained by their flat fixation disparity curves. The original conclusion was that presbyopes had learned to substitute accommodative convergence innervation for positive vergence innervation; however, more recent evidence indicates that prism adaptation may be the explanation. This was a poignant demonstration that the phoria-vergence and fixation disparity criteria are indicators of different aspects of the oculomotor system. A complete analysis of any system would include analysis of both the phoria-vergence relationships and the various fixation disparity parameters.

REFERENCES

Arner RS, Berger SI, Braverman G, Kaplan M. The clinical significance of the effect of vergence on fixation disparity—a preliminary investigation. Am J Optom 1956;33:399–409.

Borish IM. Clinical refraction. Chicago: Professional Press, 1970.

Borish IM. The Borish nearpoint chart. J Am Optom Assoc 1978;49:41–44.

Carter DB. Fixation disparity and heterophoria following prolonged wearing of prisms. Am J Optom Arch Am Acad Optom 1965;42(3):141–52.

Klecka R. Discriminant analysis. In: Statistical package for the social sciences. 2nd ed. New York: McGraw-Hill, 1975.

Lesser SK. Optometric extension program postgraduate courses. Vol. 41. Series 18, no. 4. 13–15.

Lesser SK. Introduction to modern analytical optometry. Duncan, Okla.: Optometric Extension Program Foundation, Inc., 1974.

Mallett RFJ. The investigation of heterophoria at near and new fixation disparity technique. Optician 1964;148, No. 3844, 547–551.

Mallett RFJ. A fixation disparity test for distance use. Optician 1966;152, No. 3927, 1–3.

Martens TG, Ogle KN. Observations on accommodative convergence, especially its nonlinear relationships. Am J Ophthalmol 1959;47(1):455–62.

Morgan MW. The clinical aspects of accommodation and convergence. Am J Optom Arch Am Acad Optom 1944:21(8):301–13.

Morgan MW. The analysis of clinical data. Optom Weekly 1964;27–34; 23–25.

Ogle KN, Martens TG, Dyer JA. Oculomotor imbalance in binocular vision and fixation disparity. Philadelphia: Lea & Febiger, 1967.
Percival A. The prescribing of spectacles. Bristol, England: J. Wright & Sons, 1928.
Saladin JJ, Sheedy JE. A population study of relationships between fixation disparity, heterophorias and vergences. Am J Optom Physiol Opt 1978; 55(11):744–50.
Sheard C. Zones of ocular comfort. Am J Optom 1930;7(1):9–25.
Sheedy JE. Fixation disparity analysis of oculomotor balance. Am J Optom Physiol Opt 1980a;57(9):632–39.
Sheedy JE. Actual measurement of fixation disparity and its use in diagnosis and treatment. J Am Optom Assoc 1980b;51:1079–84.
Sheedy JE, Saladin JJ. Exophoria at near in presbyopia. Am J Optom Physiol Opt 1975;52(7):474–81.
Sheedy JE, Saladin JJ. Phoria, vergence, and fixation disparity in oculomotor problems. Am J Optom Physiol Opt 1977;54(7):474–78.
Sheedy JE, Saladin JJ. Association of symptoms with measures of oculomotor deficiencies. Am J Optom Physiol Opt 1978;55(10):670–76.
Worrell BE, Hirsch MJ, Morgan MW. An evaluation of prism prescribed by Sheard's criterion. Am J Optom 1971;48(5):373–76.