A REVIEW OF OPHTHALMIC EXAMINATIONS CARRIED OUT AT AIR FORCE CENTRAL MEDICAL ESTABLISHMENT

BY

WG. CDR. T. G. JONES, *M. C.*

Adviser in Ophthalmology, Air Force School of Aviation Medicine

II. AN ANALYSIS OF THE OCULAR MUSCLE BALANCE TESTS

Introduction

In this paper the routine ocular muscle balance tests, as carried out at A. F. Central Medical Establishment from June 1956 to July 1959, are reviewed and analysed against the background of the etiology of heterophoria and the requirements for flying. The series covers 519 candidates for service and civil aircrew duties and 206 serving military and civil pilots.

The actiological basis of heterophoria [1, 3]

The ideal situation is a perfectly balanced equilibrium or orthophoria, wherein the eyes are maintained on the fixation point without stress, and without the aid of the corrective fusion reflexes, and when dissociated occupy the same position. This is an unrealized ideal. Heterophoria, or the condition, wherein the eyes are maintained on the fixation point only under stress and with the aid of the fusion reflexes, reverting to a different position when dissociated — indicating a latent imbalance, is therefore a normal condition. The tendency of the eyes to deviate off the fixation axis is counteracted and masked by the desire for fusion. If this fusion faculty is rendered ineffective partially or totally, an intermittent or permanent manifest squint supervenes. The difference between latent and manifest imbalances is therefore qualitative, depending partly on the degree of dissociation, but essentially on the individual's ability to compensate by his desire for fusion. The factors, which determine the direction and the degree of the deviation, have been classified as follows :—

(a) *Static factors* :—The topographical relationship between the eyeballs and their adnexa. Since perfect symmetry rarely exists between the muscles, the fascia, the ligaments and the intraorbital tissues, the ground is usually set for heterophoria. Asymmetry of the orbits, proptosis, enophthalmus, eccentricity of the foveae, abnormal angle gamma, wide or narrow interpupillary distances are all determining factors.

(b) *Kinetic factors* :—The accommodation — convergence synkinesis is upset by refractive anomalies. In the interests of clear vision, the fusion reflex overwhelms the accommodation — convergence reflex and the latter being very elastic, readily accepts the strain.

(i) The uncorrected hypermetrope uses accommodation in excess to obtain clear vision — resulting in esophoria. If the refractive error is small and is outgrown, the esophoria disappears.

(ii) If the hypermetropic error is very large, so that even with maximum accommodation, there is no commensurate improvement, the challenge is not accepted, and the eyes tend to diverge with resultant exophoria.

(iii) The emmetrope engaged in excessive near work and therefore constantly accommodating tends towards esophoria.

(iv) The early presbyope whose accommodation is put to strain also tends to be esophoric.

(v) In uncorrected acquired myopia, where the accommodation is not required and convergence is not stimulated, the tendency is towards exophoria. Later in life, as the near point recedes and convergence is still less required, this divergence increases.

(vi) In congenital myopia, where there is clear near vision without any effort of accommodation and the distant vision remains permanently blurred, esophoria exists.

(vii) In moderately high degrees of astigmatism, where there is no clear vision both for near and distance the condition tends to be exophoria.

(viii) In anisometropia, if the dominant eye is hypermetropic, esophoria is the rule; if the dominant eye is myopic then exophoria predominates.

(c) *Neurogenic factors* :— giving rise to an unequal distribution of power in the neuromuscular synergy.

The etiology is rarely simple, since both static and kinetic factors frequently operate together.

Ocular Muscle Balance and Flying

The present day concept places less importance to ocular muscle balance in relation to flying ability. Experience in World War II showed that whilst good vision was of prime importance in learning to fly, there was little correlation between heterophoria and success in flying [4]. What is of more importance is not the degree of heterophoria, but the liability to break-down under stresses of anxiety, fatigue, alcohol, hypoxia etc. thereby converting a latent into a manifest imbalance with its associated symptom complex, which is incompatible with flying.

Our present standards restict heterophoria, as determined by he Maddox rod test at 6 m. to 6.0 p. d. of eso and exophoria, and at 30 cms, to 16.0 p. d. of exophoria and 6.0 p. d. of esophoria; hyperphoria is limited to 1.0 p. d. at ejther distance. It is presumed that beyond these limits, there is a greater liability for a breakdown to occur. It may, however, be justifiably be argued that cases beyond these limits must possess a very good fusion sense to have maintained binocularity under such great stress and, therefore, are less liable to breakdown.

According to Neely[4], there are very few instances in which heterophoria alone was known to have caused visual difficulties in flying, there has usually been evidence of anxiety in a temperamentally unsuitable individual, in addition to a muscle imbalance of a relatively low degree.

In judging depth, a pilot relies more on monocular cues;[7] the fine stereoscopic sense employed for near visual tasks is not required. Tests for stereoscopic vision, such as the Howard Dolman, the Verhoeff machine, and the Livingston depth perception apparatus have shown no correlation with the ability to fly[4].

It is therefore evident, that in the evaluation of ocular muscle balance for flying, it is of prime importance to evaluate the fusion sense and to give more consideration to tests that evaluate the fusion sense than to those that merely measure the degree of heterophoria present.

The Ocular Muscle Balance Tests :

The ocular muscle balance tests in routine use at A. F. C. M. E. for both military and civil pilots are the following.

(a) The Maddox Rod Test performed at both 6m and 30 cms in a partially darkened room, with the rod placedtas a routine before the right eye. The rod dissociates the eyes by disturbing the image presented to the eye behind it; the partially darkened background aids in eliminating fusion — and the degree of dissociation can be accurately measured by means of correcting prisms.

(b) The Bishop Harman Diaphragm Test — This is a near distance test. It estimates the capacity for binocular fusion, but cannot of itself measure the degree of heterophoria. A card exhibiting a row of letters or figures 1 to 7 is viewed through an adjustable diaphragm, so arranged that when fully open, all the figures are seen by both eyes; As the diaphragm is closed, at a steady even pace, the area of binocular overlap is reduced till nothing is common, thus stressing the fusion sense. The breakdown point is indicated by one of the following responses :—

(i) A separation of the two halves with a "bar" in between, indicating exophoria.

(ii) A "crowding" together of the two halves indicating esophoria.

(iii) A vertical break, one half going up, and the other down, indicating hyperphoria.

(iv) A suppression of one or other half — signifying uniocularity.

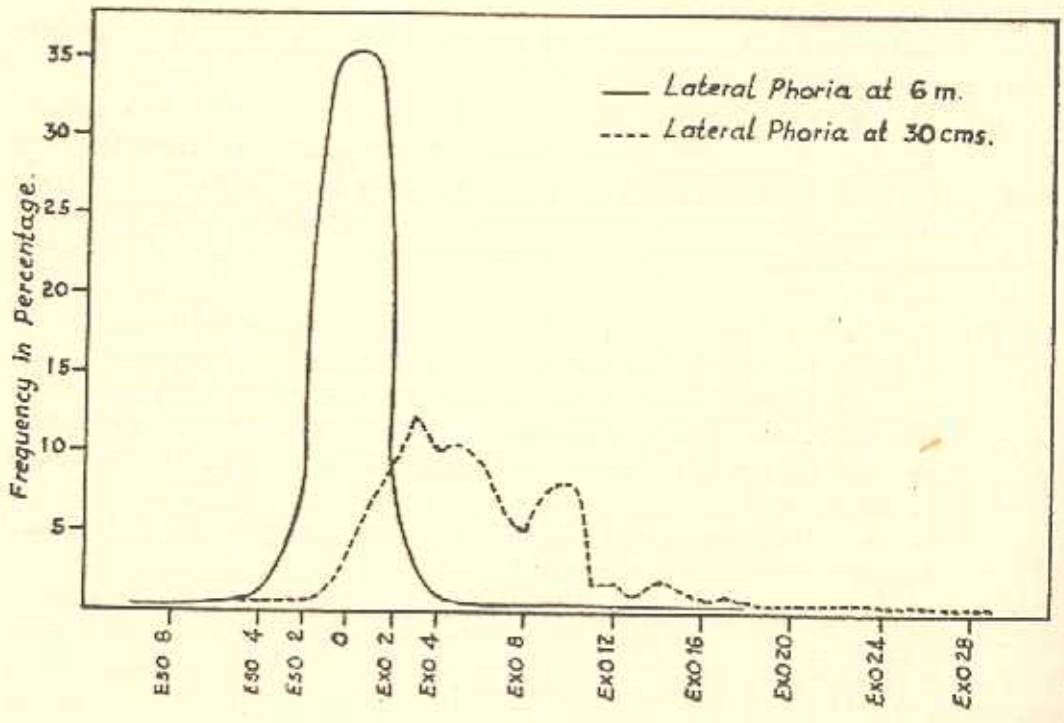
(c) The Binocular Gauge Test which determines two aspects of convergence (i) *Objective convergence* (*C*) as indicated by the observed cessation of convergence in one or both eyes and (ii) *Subjective convergence* (*SC*) or the limit of binocularity as indicated by the apparent shift of the fixated object in the direction of the dominant eye, whilst the other eye suppresses, both eyes still appearing to converge. When the two readings SC and C approximate a strong fusion sense is said to be indicated (RAF AP 130).[6] In this paper, the difference between the two is referred to as the SC–C difference.

(d) The Cover Test — This is performed with the fixation point at 6m and at 30 cms. The extent and direction of the latent deviation and its rate of recovery is noted on uncovering, and completeness of recovery is checked on covering the other eye. Uniocularity is indicated by incomplete or no recovery.

RESULTS

The Incidence of the Lateral Phorias

The incidence of the lateral phorias as determined by the Maddox rod testta both far and near distances is shown in Fig. 1.



Distribution of the lateral phorias at 6m. and 30 cms.

The curve of the lateral phorias at 6 metres shows an approximately normal distribution peaked between esophoria 1.0 p. d. and exophoria 1.0 p. d. 87.5% falling between esophoria 2.0 p.d. and exphoria 2.0 p.d. The percentage falling out of the standard limits of 6.0 p.d. eso- and exo- is 2.3%. The curve of the lateral phorias at 30 cms shows an uneven distribution, but 84.2% fall between 1.0 p.d. and 10 p.d. of exophoria, indicating a shift towards exophoria at this distance. The reason for this shift towards exophoria is that convergence has to be brought into play at this test distance of 30 cms and any deficit of convergence is manifested as an exophoria. This explains the very great frequency of bar responses on the Bishop Harman diaphragm test, which is a near distance test, and latent divergence on the near cover test, often associated with esophoric responses at distance. The percentage outside standard limits for near distance, 6.0 p.d. esophoria and 16.0 p.d. exophoria, is 3.2%.

Refraction and the Lateral Phorias

The association between refraction and the lateral phorias is shown in Tables I and II. The range of refraction in the cases under review is from — 4.0 D to + 5.0 D. Table I shows the relation between refraction and exophoria expressed in percentage values.

TABLE : I

Correlation Table showing the association between Refraction and Exophoria value at 6 m (figs. in percentage for 233 Cases)

		Exophoria at 6 m in p.d.													
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	Above 6.0	Total
Refraction in D.	+4.0			0.4											0.4
	+3.0	0.4												0.4	0.8
	+2.0	3.0	0.4	0.9	0.4		0.4	0.4							5.5
	+1.0	31.8	24.0	6.9	4.7	1.7	3.4	0.9	0.4					2.6	76.4
	0	3.9	2.6	0.9	1.7										9.1
	−1.0	2.2	2.2	0.9	1.7								0.4		7.4
	−2.0														—
	−3.0			0.4											0.4
	Total	41.3	29.2	10.4	8.5	1.7	3.8	1.3	0.4	—	—	—	0.4	3.0	100.0

The correlation coefficient was found to be negligible, as also can be observed by the absence of a linear scatter. It can be seen that the hypermetropic refractions are spread out while the majority of myopic refractions (−1.0 D) are grouped round smaller exophoric values.

Table II shows the association between refraction and esophoria at 6 m.

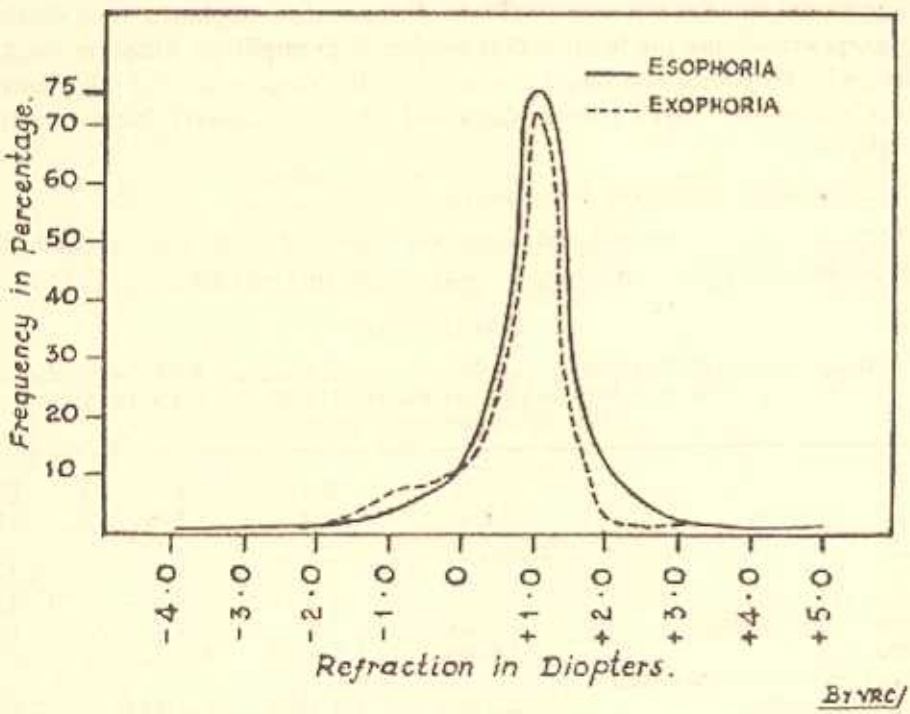
TABLE: II

Correlation Table showing the association between Refraction and Esophoria value at 6 m. (figs. in percentage for 256 cases)

Refraction in D.	Esophoria at 6 m in p.d.													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	Above 6.0	Total
+5.0		0.4	0.4											0.8
+4.0					0.8									0.8
+3.0							0.4					0.8	0.4	11.7
+2.0	2.7	4.6	2.0	0.8										
+1.0	28.5	26.1	9.7	3.9	1.2	2.0	0.4			0.4			0.8	73.0
0	2.7	2.0	1.5	0.8	0.8	0.4								8.2
−1.0	1.5		1.2		0.4	1.2	0.4							4.7
−2.0														
−3.0												0.4		0.4
−4.0						0.4								0.4
Total	35.4	33.1	14.8	5.5	3.2	4.0	1.2	—	—	0.4	—	1.2	1.2	100.0

There is again no linear scatter and the correlation coefficient was found to be negligible. The only notable feature is that higher esophoric values are predominant in the hypermetropic refractions. The readings in the last columns of the tables give the percentage distribution of the lateral phorias for the range of refractions from −4.0 D to + 5.0 D). There is a high correlation between exophoria and esophoria at each level. This is mainly due to the large incidence in almost equal proportions of both esophoria (81.2%) and exophoria (85.5%) in the range of refraction 0 to +1.0 D. A tendency towards esophoria is revealed in the hypermetropic range of + 2.0 to + 5.0 D; this is expected as this is the range of superable hypermetropia, where an excess of accommodation has to be exerted, boosting up convergence with resultant esophoria. An inference in cases of myopic refraction ranging from −2.0 to −4.0 D is not possible as there are a negligible number of cases in these refraction levels. However, of the −1.0 D refraction cases, 4.7% were distributed in esophoria against 7.4% in exophoria, revealing a tendency towards exophoria at this level. Fig. 2 illustrates the above findings.

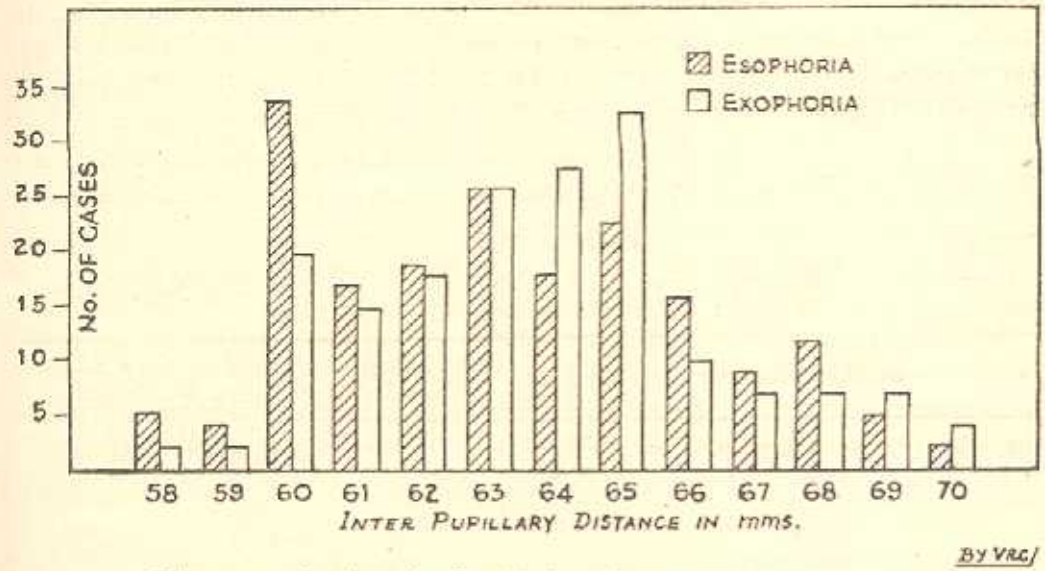
FIG. 2



Distribution of the lateral phorias at each of the refraction levels.

Inter-Pupillary Distance and Lateral Phorias

The incidence of the inter-pupillary distance in the population under review and their relationship with the lateral phorias at 6 metres is shown in Fig–3.



Histogram showing the distribution of inter-pupillary distances in relation to lateral phorias.

The modal value af the inter pupillary distance for esophoria was 60 mm, and that for exophoria 65 mm, indicating that smaller inter pupillary distances tend to be associated with esophoria and larger distances with exophoria, but the correlation coefficient between the lateral phoria values and the inter-pupillary distance was found to be negligible.

Inter-relationship between the Near distance Tests

The association between the Maddox rod values for near distance and the response in the Bishop Harman diaphragm test is shown in Table III.

TABLE III

Mean, Standard Deviation, and 80% Range of Maddox Rod Exophoric values at 30 cms. for each of the Bishop Harman's Bar Groups (for 423 cases reviewed)

	Bar 1–2	Bar 3–4	Bar 5–6	Bar 7–8
Mean (in p. d.)	6.0	6.7	8.4	11.4
Standard deviation	3.4	3 6	4.4	5.5
Mean ± S. D.	2.6–9.4	3.1–10.3	4.0–12.8	5.9–16.9
80% range of Maddox Rod exophoric values	2.0–9.0	3.0–10.0	4.0–14.0	6.0–20.0

Since, as discussed above, exphoria predominates at near distance, the values are mainly exophoric. It will be observed that there is a slow increase from 6.0 to 6·7 p. d. in the average exophoric value upto bar 4, and thereafter a rapid and progressive increase. The 80% range of these mean values is very wide, indicating the influence of the fusion sense, eg. an exophoria of 9.0 p.d. with good fusion may give a bar response on the diaphragm test between 1 and 2, and with poor fusion may give bar responses beyond 8 and may even show a uniocular response.

Table IV gives the correlation coefficients between Maddox rod exophoric values at 30 cms and the Bishop Harman diaphragm test values at various SC–C differences.

TABLE : IV

Correlation Coefficients between Bishop Harman's Bar Values and Exophoric values at 30 cms for Various SC–C Differences

SC–C difference	Correlation coefficient between Bishop Harman's & Maddox Rod value
0–5	+ 0.28
5–10	+ 0.22
10–15	+ 0.16
15–20 and above	+ 0.51

It is observed that in cases with SC-C differences of 15 and above, there is high correlation between the Maddox rod exophoric values and the Bishop Harman diaphragm test.

Table V shows the relation between the levels of objective convergence (C) and the Maddox rod values at 30 cms. It is seen that the ranges are very wide and that the maximum limits of the Maddox rod values show no linearity ; a value of Exo. 29.0 p.d being associated with an objective convergence of 6 to 7 cms. The minimum limits and mean values show a linear increase from esophoria to exophoria.

TABLE : V

Table Showing the Mean Exophoric Value at 30 cms and Range, for Several Objective Convergence Levels (for 768 Cases Reviewed).

Objective convergence in cms.	Mean lat. phoria at 30 cms.	Range.
6.0 – 7.0	Exo 5.1	Eso 8 – Exo 29
7.1 – 8.0	Exo 5.5	Eso 6 – Exo 20
8.1 – 9.0	Exo 5.3	Eso 2 – Exo 10
9.1 – 10.0	Exo 8.3	Exo 1 – Exo 22
above 10.0	Exo 11.6	Exo 5 – Exo 24

Analysis of Borderline and Below Standard cases

There were 24 cases beyond the Maddox rod standards, whose complete records were available. Of these, 9 showed uniocularity in either the Bishop Harman or Cover tests. In these, the average C was 7.7 cms, SC=21.0 cms and the SC-C difference=13.3 cms. The remaining 15 cases were binocular on the Bishop Harman & Cover tests. Their average C. was 7.4 cms, SC=15.7 cms and SC-C difference=8.3 cms. The records also included 12 cases within the Maddox rod standards, but uniocular either on the Bishop Harman's or Cover test. For these cases, the average C was 8.0 cms, SC=18.8 cms and SC-C difference=10.8 cms. It is therefore evident that larger SC-C difference are closely associated with uniocularity, and therefore the SC-C difference is a good indicator of the fusion sense. The smaller the difference (especially with a small C.) means good fusion; a larger difference indicates a poor fusion sense.

Incidence of Lateral Phoria in Serving Personnel

Table VI shows the incidence of lateral phorias in 206 serving flying personnel both Air Force and Civil.

TABLE VI

Distribution of the Lateral Phorias Observed in 206 Flying Personnel (Air Force & Civil) for Far & Near Vision as Determined by the Maddox Rod.

	Far Vision (6 m)				Near Vision (30 cms)			
	A. F.	Civil	Total		A. F.	Civil	Total	
	Number	Number	Number	Percentage	Number	Number	Number	Percentage
Exo > 20						2	2	1.0
19–20						2	2	1.0
17–18		1	1	0.5	2	3	5	2.4
15–16					2	2	4	1.9
13–14					—	8	8	3.9
11–12					1	4	5	2.4
9–10		1	1	0.5	8	21	29	14.0
7–8					6	17	23	11.1
5–6		2	2	1.0	8	27	35	17.0
3–4	1	5	6	3.0	12	23	35	17.0
1–2	25	68	93	45.0	11	25	36	17.4
Orthophoria	—	1	1	0.5	1	3	4	2.0
Eso 1–2	28	67	95	46.0	5	5	10	4.9
3–4	3	1	4	2.0	—	4	4	2.0
5–6	—	1	1	0.5	1	2	3	1.5
7–8	1	1	2	1.0	1	—	1	0.5
	58	148	206	100.0	58	148	206	100.0

The extreme is represented by a civil pilot with the following findings :—

Vision. RE—6/6 L. E. 6/5

Retinoscopy at 1m. RE +2.25 / +2.5 L.E. +2.0 / +2.25

Maddox rod test: at 6m. Rt. hyper 2.0 p. d.
Exo 18 p. d,

at 30 cms Rt. hyper 2.0 p. d.
Exo 24 p. d.

Bishop Harman diaphragm test: (i, p. d. 66 mm)
uniocular response at 20.

Convergence C=21 cms. SC=23 cms.

Cover test: Latent divergence. No recovery both for distance and near.

Ocular movements: full. No diplopia.

When, after several years of flying, this pilot was first reviewed at A. F. CME and it was discovered that he was beyond the standard limits, and had an alternating divergent squint, he was grounded. However, he was returned to flying after it was demonstrated on the synoptophore that he was capable of fusion and stereopsis with amplitude. He is at present a senior captain with more than 5,000 hours and a good flying record.

Of the nine serving pilots, beyond the near Maddox rod standards, three were presbyopes of varying degrees, which accounts for their poor ocular muscle balance at near distance. Table VII compares the means and ranges of our study with those of 250 Naval aviators reviewed by Imus.[2]

TABLE VII

Mean and Range of Lateral Phoria Values for the Distribution in Table VI as Compared with the Mean & Ranges obtained by Imus [2].

	Present Study		Imus	
	Far	Near	Far	Near
Mean	0.03 p.d. Eso	5.69 p.d. Exo	0 36 p.d. Eso	6.84 p.d. Exo
95% range	2.0 p.d. Eso to 4.0 p.d. Exo	6.0 p.d. Eso to 16.0 p.d. Exo	4.0 p.d. Eso to 4.0 p.d. Exo	5.0 p.d. Eso to 18.0 p.d. Exo
Total range	8.0 p.d. Eso to 18.0 p.d. Exo	8.0 p.d. Eso to 24.0 p.d. Exo	6.0 p.d. Eso to 6.0 p.d. Exo	8.0 p.d. Eso to 18.0 p.d. Exo

Conclusions

1. An analysis of the incidence of the lateral phorias, as determined by the Maddox rod test at 6 m, shows that 87.5% of cases fall between esophoria 2.0 p. d. and exophoria 2.0 p.d. At 30 cms. 84.2% range between 1 to 10.0 p. d. of exophoria. This shift towards exophoria at near distance is due to the fact that an exphoric response results from any deficiency in the convergence that must necessarily be exerted at this distance. The total percentage falling outside the Maddox rod limits at 6 m. is 2.3% as compared to 4% as observed by Neely [4], Nichols [5] and Scobee [8]. The percentage falling outside the limits at 30 cms is 3.2%.

2. The refraction of the cases under review ranged from —4.0 D to + 5.0 D. There was a very high incidence in almost equal proportions of both esophoria and exophoria in the range 0 to + 1.0 D. There was a shift towards esophoria in the range + 2.0 to + 5.0 D. This is in accordance with the known etiology, since this is the range wherein excess accommodation has to be exerted to obtain clear vision resulting in a boost up of convergence. A tendency towards esophoria was noted with refractions of — 1.0 D. This too is expected as less accommodation is required and convergence is not well stimulated at this refraction level.

3. The relationship of the interpupilary distances with the lateral phorias was in accordance with the known etiology that smaller interpupillary distances tend to be associated with esophoria, and the larger with exophoria. The correlation coefficient, however, was negligible.

4. The analysis of the near distance tests show that the Bishop Harman diaphragm test values are associated with a wide range of near distance Maddox rod values, dependent upon the fusion sense. The greater the fusion sense the smaller the Maddox rod value.

5. The Maddox rod Test by itself, as done on routine, does not reveal tendencies towards uniocularity. Uniocular tendencies were revealed only by the Bishop Harman diaphragm test and the Cover test.

6. The difference between subjective and objective convergence (the SC–C difference) is an excellent indicator of the fusion sense. It tends to be large in the cases exhibiting uniocularity, whether these be within or beyond the Maddox rod standards. A SC–C difference of 10 cms and above appears to be closely associated with uniocularity. The SC–C difference is therefore of great value in the assessment of borderline cases.

7. Of the 206 serving pilots reviewed one was uniocular; he has amassed considerable flying experience and is flying successfully. Presbyopia accounts for a third of the cases outside the near distance exophoria limits.

Acknowledgement

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