BINOCULAR MECHANISMS IN SMALL-ANGLE STRABISMUS*

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THE purpose of treatment of all patients with strabismus is to reduce the angle of deviation to the smallest possible value and to develop the co-operation between the eyes to the highest possible degree. Normal binocular use of the eyes may be achieved in patients with fully accommodative squints of late onset and relatively short duration, but this is not always the case even in patients who show strong fusion and stereopsis on the major amblyoscope. A certain number of such patients have a definite slight deviation on cover test at all distances; others have a manifest deviation for one distance only, arousing the suspicion that binocular vision may not be perfect even at those distances at which the cover test reveals no deviation; the subsequent history may demonstrate a tendency for the strabismus to recur; and in others the depth perception may be surprisingly poor (Naylor, Shannon, and Stanworth, 1956).

One possible obstacle to perfect binocular vision in such patients is abnormal retinal correspondence with a very small angle of anomaly; this may be very difficult to detect and to interpret, so that there is little unanimity of opinion regarding its importance. There is no doubt that a number of patients with small-angle strabismus show, on a variety of tests, a difference between the objective and subjective angles of squint (Jampolsky, 1951; Levinge, 1953), but this in itself does not prove that abnormal retinal correspondence is present during everyday use of the eyes, and some surgeons (*e.g.* Cashell, 1954) consider that a more likely explanation of the condition is that an abnormally large degree of fixation disparity is present. Fixation disparity, which is a normal condition in most subjects with heterophoria, is a minute strabismus occurring in binocular single vision, the slightly disparate images from the two eyes being nevertheless fused to give binocular single vision. An obvious deduction is that patients who have apparently had their squint cured may in fact be left with fixation disparity and a squint which, though small, is nevertheless of clinical significance. Careful performance of the "cover-uncover" test has indeed shown that some such patients have a small manifest deviation, sometimes described as a "flick". Others show the even more characteristic partial recovery of the squinting eye towards the straight position; the small degree of convergence still remaining will be seen if the other eye is then covered, for the squinting eye will then make a further movement to take up fixation. Since these movements may be small, it is conceivable that some patients may have fixation disparity of

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clinical significance which is not detectable on cover test, for movements of less than two dioptres are not readily visible even in co-operative patients.

The third possible factor in these patients is suppression; even in small-angle strabismus, in which the mechanisms of fixation disparity or abnormal retinal correspondence might be expected to operate, the patient might still utilize suppression as a means of avoiding diplopia, and it is conceivable that such suppression may be much more in evidence in everyday conditions than in the artificial situation presented by routine testing on the major amblyoscope.

The modified major amblyoscope (Stanworth, 1958) makes possible the assessment of very small deviations during virtually normal binocular viewing conditions, and might therefore be expected to help in the elucidation of these problems. In this instrument, the opaque mirrors incorporated in each arm of the routine major amblyoscope are replaced by transparent mirrors, so that the patient can see through them with both eyes simultaneously to a distant target, thus providing a natural binocular fusion stimulus; the eyes therefore take up the position which they assume in everyday life. At the same time images can be projected on to each retina from the slide-holders in each arm of the instrument, the transparent mirrors acting as reflecting surfaces for this purpose; these images act merely as markers which indicate the objective and subjective angles of squint and do not influence the positions of the eyes.

For accurate measurement of these angles, slides depending on vernier alignment are used: *i.e.*, in measuring the subjective angle, a dot seen by one eye has to be placed in a gap in a vertical line seen by the other eye (Stanworth, 1958, Fig. 5*d*). If normal correspondence is present, this angle gives the objective angle of squint directly; abnormal retinal correspondence is indicated by ocular movement on alternate flashing at the subjective angle. Since ocular movements of less than two dioptres cannot be seen, abnormal retinal correspondence of less than this degree would not be detected. Suppression is manifest in the same way as on the routine instrument, the dot tending to go in and out of the gap. Fusion is measured with prisms placed in the eye-pieces, the range of powers over which the slides remain superimposed being the measure of the range of fusion; peripheral fusion is measured by covering the central portion of the distant target with a matt green circle. Interrupted reading can easily be carried out using slides which present alternate words to each eye. The practical details of the measurements are described elsewhere (Stanworth, 1958; Stanworth and da Cunha, 1959).

Present Investigation

It is the purpose of this paper to describe, with illustrative cases, the various binocular mechanisms which have been found to be present in everyday use of the eyes. The cases are taken from patients with fusion and stereopsis

attending the Orthoptic Department, eighty of whom have been fully investigated; a numerical analysis of the results has been given elsewhere (Stanworth and da Cunha, 1959). In the majority of patients, three readings of the subjective angle were taken with the dot presented to the right eye and the line to the left eye, and three further readings with the slides interchanged; the arms of the instrument were read to 0.5 prism dioptre or occasionally to 0.25 prism dioptre, and the average of the six readings was taken to be the required measurement. This gives values measured in twelfths of a dioptre, but it is not intended to imply that the accuracy of measurement is of this order. The readings were repeated using a 10° green circle to eliminate central fusional stimuli. The amplitudes of central and peripheral fusional movements were measured where possible, and a test for interrupted reading was carried out. In many patients, depth perception was measured by the method of Naylor and Stanworth (1959) and expressed as an angle of binocular parallax.

Patients with Normal Retinal Correspondence

It will be most convenient to describe first those patients who have normal correspondence, in whom the subjective angle corresponds with the objective position of the eyes. If bifoveal fixation is perfect during normal binocular use of the eyes, the reading on the modified major amblyoscope will average zero; this will be the case even if, on dissociation, a phoria can be shown to be present. Within the limits of the present technique, this is the case in normal subjects; we have taken the upper limit of normal to be an average reading of 0.5 dioptre with the whole target, and one dioptre with a green circle of 10° diameter. Some patients who, on cover test, have no deviation nevertheless show a definitely abnormal angle on the major amblyoscope, because of an abnormally large amount of fixation disparity:

Case 1, a boy aged 5 years, had had an intermittent accommodative convergent squint since the age of one year.

The visual acuity with and without correction for a small degree of hypermetropia was 6/9 in each eye.

The cover test with and without glasses showed no deviation.

Routine major amblyoscope readings showed an angle with glasses of +2°, with a range of fusion from -5° to +8°, and stereopsis; without glasses the angle was +5°.

The modified major amblyoscope without glasses (which he did not normally wear), gave an average angle of 1.25 prism dioptres with the whole target, with a fusional range from 1 prism dioptre base-in to 5 prism dioptres base-out. With the 10° green circle the average angle was 1.66 prism dioptres with fusional range from 2 dioptres base-in to 5 dioptres base-out. He had no difficulty in carrying out the readings, there being no evidence of suppression. Interrupted reading was also carried out without difficulty. Depth perception was poor (worse than 200 seconds).

In some otherwise similar patients, elimination of central fusional stimuli by the use of the green circle reveals a much larger degree of fixation disparity than is indicated by the use of the whole target:

Case 2, a boy aged 7 years, had had a partially accommodative left convergent squint since the age of 4 years, for which a recession of the left medial rectus had been performed when he was 5 years old.

The visual acuity with correction for a small degree of hypermetropic astigmatism was 6/9 in each eye.

The cover test with glasses showed no deviation for distance but a small manifest right convergent strabismus for near; without glasses, the convergent squint was present for near and distance.

Routine major amblyoscope readings with glasses showed an angle of $+8^\circ$, with fusional range from $+4^\circ$ to 20° , with a tendency to right suppression; stereopsis was present.

The modified major amblyoscope gave an average angle with the whole target of $+1.33$ prism dioptres, rising to $+4.5$ dioptres with the green circle; the range of fusion with the whole target was from 3 prism dioptres base-in to 2 prism dioptres base-out, but with the 10° green circle was only from one prism dioptre base-in to one prism dioptre base-out, and the readings were not very reliable. Interrupted reading was carried out without difficulty; depth perception was poor (worse than 200 seconds).

When larger degrees of fixation disparity are present the deviation may be visible on cover test, in which case the modified major amblyoscope often gives evidence of suppression, which may or may not be present on the routine instrument:

Case 3, a girl aged 6 years, had had a partially accommodative right convergent squint with amblyopia since the age of 5 years, which had been treated by occlusion and by recession of the right medial rectus muscle.

The visual acuity with correction for a small degree of hypermetropic astigmatism was 6/9 in the right eye and 6/6 in the left.

The cover test for distance with glasses showed right fixation disparity with partial recovery, with a marked tendency to break down to a manifest strabismus; for near, she had a manifest right convergent strabismus.

Routine major amblyoscope readings showed an objective angle with glasses of $+6^\circ$, the subjective angle being $+3^\circ$ with a tendency to right suppression; the range of fusion was from -2° to $+10^\circ$ and stereopsis was present.

The modified major amblyoscope gave an average angle with the whole target of 2.33 dioptres, but the dot kept moving in and out of the gap in the lines; the range of fusion was from one prism dioptre base-in to 5 prism dioptres base-out, at which point binocular co-operation broke down and the eyes became much more convergent. With the 10° green circle, suppression was equally obvious, the average angle being $+3$ dioptres, with no obvious prism vergence. Interrupted reading showed right suppression, but by this time, after a long period of testing, a manifest squint was almost constantly present. Depth perception was poor (worse than 200 seconds).

In some patients, usually with a more obvious degree of amblyopia, suppression may be so marked that it is impossible to measure accurately either the angle of squint or the magnitude of the fusional range, though fusion can be shown to be present as in the following case:

Case 4, a girl aged 7 years, had had a left accommodative convergent squint with

amblyopia since the age of 4 years, which had been treated by occlusion and by orthoptic treatment with the major amblyoscope.

The visual acuity with correction of a moderate degree of hypermetropia was 6/5 in the right eye and 6/12 in the left.

The cover test for distance and near with glasses showed a small manifest convergent squint, possibly with partial recovery.

Routine major amblyoscope readings showed an objective angle with glasses of $+4^\circ$, the subjective angle being $+2^\circ$; fusion was at 0° , with fusional range from -9° to $+16^\circ$.

The modified major amblyoscope showed suppression which was so marked that accurate readings were impossible but the subjective and objective angles were between nil and 3 prism dioptres; when increasing strengths of prisms were inserted, this reading was unchanged until a 10-dioptre prism was inserted, at which point the binocular co-operation broke down, the eyes converged and the readings increased to 10 prism dioptres. Depth perception was about 101 seconds.

Not all patients with marked suppression of this type have obvious fixation disparity, for it may occur with an angle of squint indistinguishable from zero.

In some patients, the range of fusion may be so small as to be virtually absent, but the presence of fixation disparity is strongly suggested by consistent readings of the angle, together with the ability to perform interrupted reading.

Occasionally patients give one or two preliminary readings which are much larger than the subsequent ones, indicating that the eyes are first dissociated by the presence of the instrument, but that the stimulus to fusion produced by the distant target then quickly produces the position the eyes take up in daily life; in such patients the first readings should be discarded. More commonly the first readings are consistent and reliable, but occasionally larger readings are produced, indicating a momentary breakdown of fusion; or the breakdown may be long lasting, especially after the range of fusion has been measured, and the patient may take some time to recover a binocular position. In such patients, the readings may have to be repeated on another occasion in order to obtain a reliable indication of the use being made of the eyes in normal life. In only one patient has such a repetition of the test failed to indicate some form of binocular vision in a patient in whom the cover test would lead us to expect binocular vision to be present:

Case 5, a boy aged 7 years, had had a partially accommodative right convergent strabismus since the age of $3\frac{1}{2}$ years, for which he had had orthoptic treatment followed by bilateral resection of the lateral recti at the age of 6 years.

The visual acuity with correction of a moderate degree of hypermetropic astigmatism was 6/6 in each eye.

The cover test with and without glasses at distance and near showed esophoria with rapid recovery, without any tendency to break down to a manifest deviation.

Routine major amblyoscope readings showed an angle with glasses of $+10^\circ$, with a range of fusion from $+5^\circ$ to $+18^\circ$, and stereopsis, with a tendency to right eye suppression.

The modified major amblyoscope gave an angle of 20 prism dioptres on two separate occasions; there was a marked tendency to right eye suppression. Depth perception was very good, about 12 seconds.

In this patient, the modified major amblyoscope obviously produced over-convergence and the readings were of no value in indicating the everyday position of the eyes.

Some patients with amblyopia in one eye may be kept straight largely by peripheral fusion, the prism ductions with the green circle being then as strong or stronger than with the whole target, but this is not always the case:

Case 6, a boy aged 10 years, had had a left convergent squint with amblyopia since the age of 5 years, which had been treated by occlusion and by recession of the left medial rectus muscle at the age of 7 years.

The visual acuity was 6/6 in the right eye and 6/18 in the left. No glasses were worn for the small degree of hypermetropic astigmatism.

The cover test showed no deviation for distance and left convergent strabismus for near.

Routine major amblyoscope readings showed an angle of $+10^\circ$, with a range of fusion from 0° to $+15^\circ$, and stereopsis.

The modified major amblyoscope gave an average angle with the whole target of $+0.5$ prism dioptre, but with the 10° green circle the angle was $+7$ prism dioptres with suppression of the left eye. With the whole target, abduction was present to 4 prism dioptres and adduction to 16 prism dioptres, but between 8 and 16 prism dioptres there was a marked delay before the ocular movements fully compensated for the prisms. No prism vergence could be elicited with the green circle. Depth perception was about 50 seconds.

In this patient the fusion which kept his eyes straight was presumably paramacular rather than peripheral, and was, therefore, eliminated by the 10° green circle used. The large range of fusion with the whole target was explained by the fact that he was older than most of the other patients, and was intelligent enough to give time for the fusion stimulus to take effect.

In some patients, fixation disparity may, like heterophoria, become decompensated and so give rise to a manifest strabismus:

Case 7, a girl aged 9 years, had had an intermittent alternating convergent squint since the age of 4 years, for which a resection of the right lateral rectus and recession of the right medial rectus muscle had been performed at the age of 8 years, with pre-operative and post-operative orthoptic treatment.

The visual acuity with correction for a small degree of hypermetropia was 6/6 in each eye.

The cover test with glasses showed slight esophoria with apparently full recovery for distance, more marked for near, with a tendency to break down to manifest left convergent strabismus.

Routine major amblyoscope readings showed an angle of 0° with range of fusion from -5° to 20° , and stereopsis.

The modified major amblyoscope showed fixation disparity of 0.5 to 1 prism dioptres, with a tendency on occasions to break down to 6 to 8 prism dioptres.

Two separate examinations 4 and 10 months later showed on the cover test a constant alternating strabismus, mainly right, for near and distance; the modified instrument gave readings of 14 prism dioptres on the first occasion and 35 prism dioptres on the second.

In this type of patient, the fixation disparity is obviously not sufficiently well established to maintain the *status quo* indefinitely. Readings on the modified instrument may indeed give some idea whether or not the disparity is well established. Evidence of suppression (Case 3), especially with variable readings of the angle (Case 4), a momentary (Case 7) or complete breakdown during the tests, especially if this occurs during the straightforward measurements of the angle of squint before the additional strain of the measurement of prism vergence has been imposed, and a very restricted prism vergence, are all reasons for presuming that the disparity is not well-established.

Similarly, a patient may at one time give modified major amblyoscope readings and a cover test which indicate no deviation, but then break down to fixation disparity:

Case 8, a girl aged 6 years, had had a left accommodative squint since the age of 3 years.

The visual acuity with correction of a moderate degree of hypermetropic astigmatism was 6/6 in the right eye, and 6/9 in the left.

Routine major amblyoscope readings showed an objective angle of $+10^\circ$ and subjective angle of $+5^\circ$ with a range of fusion from -4° to $+20^\circ$; stereopsis was present.

The cover test with glasses at first showed esophoria for distance, with full recovery, and the readings on the modified major amblyoscope averaged less than 0.5 prism dioptre, except that occasionally she gave readings of 4 to 8 prism dioptres. Adaptation to prisms undoubtedly occurred, though the power of the prism that could be overcome varied considerably. After this examination, repetition of the cover test showed definite slight fixation disparity in the left eye with partial recovery; repetition of the readings on the modified instrument then showed fixation disparity with an angle of 8 prism dioptres.

Patients with Abnormal Retinal Correspondence

It will not have escaped notice that some of the patients with fixation disparity described in the previous section, who had normal correspondence on the modified major amblyoscope, had shown a difference in the objective and subjective angles when tested on the routine major amblyoscope (Cases 4 and 8). The number of patients who showed definite abnormal retinal correspondence on the modified instrument was, however, small. The following patient showed the condition clearly:

Case 9, a boy aged 7 years, had had an alternating convergent squint since the age of 2 years.

The visual acuity with correction of a moderate degree of hypermetropic astigmatism was 6/12 in each eye.

The cover test with glasses showed a small right convergent squint with the ability to alternate.

Routine major amblyoscope readings showed an objective angle of 0° ; fusion was present at 0° , with a range of fusion from -5° to $+10^\circ$, and stereopsis; there was some suppression, mainly right, on testing with foveal slides.

The modified major amblyoscope revealed an objective angle which was clearly convergent, but the subjective angle with the whole target and with the green circle was -2

prism dioptres; the images of the slides remained superimposed with prisms up to 3 prism dioptres base-in or base-out. Interrupted reading was carried out without difficulty.

In this patient, it was impossible to be certain whether the eyes actually converged or diverged or whether the adaptation to the prisms was merely a subjective one, the eyes remaining still and the angle of anomaly being subjectively adjusted to the prisms. Sometimes, however, it can clearly be shown that both objective and subjective adaptation can take place:

Case 10, a girl aged 12 years, had had a right accommodative convergent strabismus with amblyopia since the age of 5 years, which had been treated by occlusion and by means of the major amblyoscope.

The visual acuity with correction of a moderate degree of hypermetropic astigmatism was 6/6 in the right eye and 6/7.5 in the left.

The cover test with glasses showed alternating, mainly left, convergent strabismus for distance and near.

Routine major amblyoscope readings showed an objective angle of $+8^\circ$, and a subjective angle of $+2^\circ$, with fusion at 0° , and a range of fusion from -4° to $+4^\circ$, with suppression on testing stereopsis.

The modified major amblyoscope gave an average subjective angle with the whole target of -0.16 prism dioptre, and with the green circle of $+0.16$ prism dioptre, but the eyes were convergent. With the whole target, the eyes clearly converged further when base-out prisms up to 5 prism dioptres were introduced; with the green circle, the eyes objectively converged with base-out prisms up to 6 prism dioptres, but at 7 prism dioptres the eyes straightened, though the patient still maintained that the pictures were superimposed; with stronger prisms the slides were no longer seen superimposed. Interrupted reading was carried out without difficulty.

Occasionally abnormal retinal correspondence may be combined with suppression, in which case the subjective angle of squint is liable to be variable and the retinal correspondence inharmonious:

Case 11, a boy aged 10 years, had had a left convergent accommodative strabismus with amblyopia since the age of 4 years, which had been treated by occlusion.

The visual acuity with correction of a fairly marked hypermetropic astigmatism was 6/9 in the right eye, and 6/12 in the left.

The cover test with glasses showed a manifest left convergent strabismus for near and distance.

Routine major amblyoscope readings showed objective and subjective angles of $+12^\circ$ and $+8^\circ$ respectively, with fusion at $+8^\circ$, a range of fusion to $+4^\circ$, and stereopsis at the subjective angle.

The modified major amblyoscope showed marked left suppression, the subjective angle with slides of the larger S.P. type being 2 to 5 prism dioptres, the objective angle being about 20 prism dioptres.

In one patient the angle of anomaly was extremely small:

Case 12, a girl aged 14 years, had had a left convergent squint since the age of 3 years.

The visual acuity without correction was 6/6 in the right eye, and 6/18 in the left.

The cover test showed a very slight constant left convergent squint.

Routine major amblyoscope readings showed objective and subjective angles of $+4^\circ$ and -2° respectively, with fusion at 0° and adduction to $+10^\circ$.

The modified major amblyoscope gave an average subjective angle of -0.83 prism dioptre, with a range of fusion of only one prism dioptre each way. The objective angle was only very slightly convergent. Readings with the green circle were not carried out, and the patient did not attend for further testing.

In this patient the difference between the objective and subjective angles could easily have been missed if its presence had not been suggested by the readings on the routine major amblyoscope and by the fact that the subjective angle was significantly negative, which is unlikely to be the case in any convergent squint with normal correspondence.

Cases in which Interpretation may be Difficult

The typical cover test in fixation disparity is one in which partial recovery to a lesser angle of deviation occurs with one eye only; a similar partial recovery of the deviating eye when either eye is fixing has been interpreted by Levinge (1953) as an indication of abnormal retinal correspondence. Such a cover test may be associated with readings typical of fixation disparity:

Case 13, a girl aged 6 years, had had a left accommodative convergent strabismus since the age of 4 years, for which a short course of orthoptic treatment had been given.

The visual acuity with correction of a small degree of hypermetropic astigmatism was 6/12 in the right eye, and 6/9 in the left.

The cover test with glasses showed convergence with partial recovery in each eye, more marked when fixing with the right eye; this cover test had been seen several times in the orthoptic department.

Routine major amblyoscope readings showed objective and subjective angles of $+5^\circ$, with fusion at $+5^\circ$, positive fusional reserve to $+20^\circ$, and stereopsis.

The modified major amblyoscope, using the "dot and line" slides, gave an average angle when the dot was seen by the right eye of 3 prism dioptres, and when the dot was seen by the left eye of 1.16 prism dioptres, with a range of fusion from 2 prism dioptres base-in to 6 prism dioptres base-out. With the green circle the average angle was 3 prism dioptres, with a range of fusion from 3 prism dioptres base-in to 7 prism dioptres base-out. Interrupted reading was carried out without difficulty; depth perception was about 150 seconds.

The variation in the readings with the "dot and line" slides according to whether the dot is seen by the right or left eye has been noticed in other patients in whom the cover test is consistent with fixation disparity of the usual unilateral type; in these cases the larger or more variable readings of the angle of fixation disparity have occurred when the dot was seen by the eye in which the disparity was present on cover test, and may be associated with some suppression in this eye.

In a second patient the cover test showed partial recovery in each eye after the tests on the modified major amblyoscope had been completed, but had previously shown esophoria with good recovery, the readings on the modified

instrument showing no appreciable subjective angle of squint. In a third patient (Case 8 above) bilateral partial recovery had been noted on routine testing in the orthoptic department, but when seen for special testing, the cover test showed either esophoria or left fixation disparity.

A somewhat similar cover test occurs in which one eye, when it deviates, shows the typical partial recovery of fixation disparity, but the patient can nevertheless maintain fixation with this eye, the other eye then showing a small manifest deviation without recovery:

Case 14, a girl aged 7 years, had had a right accommodative convergent strabismus with amblyopia since the age of 3½ years, which had been treated by occlusion and by means of the major amblyoscope.

The visual acuity with correction of a moderate degree of hypermetropic astigmatism was 6/9 in each eye.

The cover test with glasses showed left fixation disparity with partial recovery for near and distance, but with the ability to maintain fixation with the left eye for near.

The routine major amblyoscope readings showed an objective angle of $+5^\circ$, the subjective angle being 0° ; fusion was attempted but was not well established.

The modified major amblyoscope gave an average angle of 1.5 prism dioptres with a range of fusion from 2 prism dioptres base-in to 3 prism dioptres base-out. With the green circle, the average angle was 2.16 prism dioptres, but no compensation for prisms could be elicited. Interrupted reading was carried out without difficulty. Depth perception was poor.

Even more difficulty in interpretation arises in the following patient:

Case 15, a girl aged 8 years, had had right convergent strabismus with amblyopia since the age of 2½ years, which had been treated by occlusion, resection of the right lateral rectus muscle at the age of 4 years, and post-operative orthoptic treatment.

The visual acuity with correction of a moderate degree of hypermetropic astigmatism was 6/9 in the right eye, and 6/6 in the left.

Routine major amblyoscope readings showed an angle of $+5^\circ$, with a range of fusion from -3° to $+17^\circ$, and stereopsis.

She was examined on the modified instrument on two occasions. On the first occasion, when the cover test for distance showed right fixation disparity, the average angle was 0.33 prism dioptre with the whole target, with a range of fusion from 4 prism dioptres base-in to 6 prism dioptres base-out; the angle with the green circle was rather variable, from 1 to 5 prism dioptres; interrupted reading was carried out without difficulty.

On the second occasion, 6 months later, the cover test showed a very small manifest right convergent strabismus with no recovery; the average angle with and without the green circle was 1.33 prism dioptres; fusional reserve was demonstrated only to 2 prism dioptres base-in with the whole target, with no compensation for prisms base-out, and suppression of the left eye occurred on attempting interrupted reading.

In this patient, subjective readings indicating no deviation were obtained on one occasion and possibly fixation disparity on a subsequent occasion, but no definite correlation between these findings and the cover test was observed.

Discussion

It will be noted that these patients with small-angle strabismus may show four basic responses during normal binocular viewing conditions:

- (a) No deviation present, within the limits of accuracy of the measurements.
- (b) Fixation disparity of more than 0.5 prism dioptre with the whole target, or more than 1 prism dioptre with the green circle.
- (c) Small-angle strabismus with suppression.
- (d) Small-angle strabismus with abnormal retinal correspondence.

Some patients fall clearly into one or other of these categories. Clinical experience would lead one to expect, as is indeed the case, that some patients with heterophoria might at one time show no deviation, but might on another occasion show a small-angle strabismus with suppression, and it is not surprising that patients who show fixation disparity on one occasion may also show a small-angle strabismus with suppression on another occasion. Indeed it might be expected that patients who, on the cover test, appear to have esophoria with good recovery might show a greater tendency to break down to a condition of manifest strabismus if the recovery was in fact only to a position of fixation disparity, since this could not be expected to provide such strong fusion.

A rather more unexpected finding was that a patient may show readings indicating no deviation on one occasion and marked fixation disparity on another occasion (*e.g.* Case 8). One is accustomed to think of fixation disparity as a fixed condition, and this may well be the case in many patients with definite but slight amblyopia which can be expected to act as a bar to perfect bifoveal fixation. Such amblyopia is not, however, invariable in fixation disparity, for subjects with normal vision who have never had a squint show slight degrees of fixation disparity, and some of the patients described here (Cases 1, 2, and 7) had equal visual acuity in the two eyes. In such patients any suppression which occurs during binocular use of the eyes must be facultative rather than obligatory, and it would not be surprising if the degree of suppression and of fixation disparity varied from time to time. This may be the explanation for the impression that fixation disparity is relatively rare in adults (Lyle, 1954), for there might be a genuine decrease in the incidence of the condition with age if patients who show this variability when young tend to improve the accuracy of bifoveal fixation as they grow older.

In patients with fixation disparity which is not well-established, and which tends to break down to show a manifest strabismus with suppression, further treatment either by orthoptic methods or by operation might be considered, the aim being to stabilize the fixation disparity in much the same way as treatment has been suggested to stabilize abnormal retinal correspondence

(Levinge, 1953). The readings on the modified major amblyoscope might, as described above, help to indicate whether or not the fixation disparity is well-established. Orthoptic treatment would, however, be contraindicated in a patient such as Case 8, who sometimes showed no deviation, since any attempt at orthoptic treatment would be likely first to produce and then to confirm the disparity; in the absence of treatment there is a reasonable chance that the eyes will stabilize in the position of no deviation.

The facultative nature of fixation disparity in some patients makes possible the interpretation along similar lines of those (*e.g.* Case 13) who show partial recovery of the deviating eye when either eye is fixing. Both the cover test and the readings on the modified major amblyoscope are consistent with fixation disparity seen first in one eye and then the other. The readings on the modified instrument are not consistent with abnormal retinal correspondence unless it be assumed that the abnormal correspondence is inharmonious and variable and that the angle of anomaly is so small that the difference between the objective and subjective angles could not be detected; these assumptions are not entirely without foundation, since inharmonious abnormal correspondence (Case 11) and very small angles of anomaly (Case 12) do exist, but the condition is much more simply explained as alternating fixation disparity. This explanation seems even more likely when it is remembered that, in normal subjects with heterophoria, fixation disparity may occur in either eye or even in both eyes simultaneously (Ogle, 1950). Moreover, the cover test described in Case 14 in which fixation disparity with partial recovery in one eye was combined with ability to maintain fixation with this eye and to squint with the other eye, may be explained on similar lines, the condition being essential alternating fixation disparity in which the partial recovery typical of the disparity was large enough to be seen in only one eye.

In general, the modified major amblyoscope does not indicate which eye has fixation disparity, so that the diagnosis of alternating fixation disparity could be made only on the cover test; thus it is possible that, in some patients with small degrees of fixation disparity which are not appreciable on the cover test (*e.g.* Cases 1 and 2), the disparity may be of the alternating type.

The patient (Case 15) whose cover test showed fixation disparity when the modified major amblyoscope readings indicated no deviation may have had a variable type of small-angle squint, similar to that in Case 8, and this is perhaps the most likely explanation of the findings. Nevertheless, it is possible that she may have had abnormal retinal correspondence with a small angle of anomaly which could not be detected under the conditions of the test, similar to, but even smaller than, that seen in Case 12. If this possibility is accepted, then the cover test would be the only indication that such a patient, giving readings indicating no deviation, has a small squint with abnormal retinal correspondence, and if the angle of anomaly were less

than 2 prism dioptres even the cover test would fail to indicate its existence; the possibility that such an erroneous diagnosis might be made is discussed elsewhere (Naylor and Stanworth, 1959) in conjunction with the results of depth perception tests.

It is highly likely that such small angles of anomaly may indicate a condition somewhat different from that usually meant by abnormal retinal correspondence, and it may be that it is to some extent a result of the conditions in which the test is carried out. In measurements of fixation disparity, a small central area is usually left in which binocular stimuli are not present (Ogle, 1950); in these circumstances the stimuli seen uniocularly are projected correctly in accordance with the primary visual direction of the retinal elements involved, and the subjective readings therefore give an accurate indication of the objective position of the eyes. If binocular stimuli are close to the uniocular stimuli, as when the whole target is used in the modified major amblyoscope, this projection may be altered. There is then a tendency for the uniocular stimuli to be projected in the direction of the adjacent binocular stimuli, which, in the eye with the fixation disparity, are projected in a direction other than the primary visual direction of the retinal elements involved in order to maintain binocular single vision in spite of the deviation of the eyes. In these circumstances, therefore, an apparent anomalous correspondence could occur, and the distinction between fixation disparity and abnormal retinal correspondence with a small angle of anomaly could become rather indefinite.

It would be expected that, if this were the explanation of all cases with a small angle of anomaly, the anomaly would disappear when the green circle was used, as in Case 15. This is not always so (Cases 9 and 10), and either true abnormal retinal correspondence occurs in these patients, or the apparent abnormal correspondence produced in fixation disparity by the mechanism described above has become so fixed that it persists even in conditions which might be expected to eliminate it. Some such mechanism is presumably responsible for the difference between the objective and subjective angles on the routine major amblyoscope in patients with fixation disparity (*e.g.* Cases 4 and 8).

A similar mechanism may explain the findings in those patients (*e.g.* Case 2) in whom the subjective angle of deviation with the whole target is much less than that with the green circle, or is even absent altogether. The difference could also be due to the different degrees of fixation disparity allowed by central and peripheral fusional stimuli; the relative importance of these two possible explanations is discussed elsewhere (Naylor and Stanworth, 1959).

Summary

The various binocular mechanisms which have been found to be present in everyday use of the eyes in patients with small-angle strabismus are described.

It is shown that almost all possible combinations of bifoveal fixation, fixation disparity, abnormal retinal correspondence, and suppression may occur. It is suggested that the distinction between fixation disparity and abnormal retinal correspondence with a small angle of anomaly may be an indefinite one.

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