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THE CENTRING OF SPECTACLE LENSES.

By MR. W. A. DIXEY, *Member.**Read before The Optical Society on March 22nd, 1900.*

IN dealing with the subject of the centring of spectacle lenses, it is necessary at first to define what we mean by the centre of a spectacle lens. Because throughout this paper I intend to disregard the thickness of the lens, and the position of nodal points. They do not affect the problems which the subject will present; and for our present purpose we may define the centre of a spectacle lens as that part of the lens through which light passes without deviation; or, more exactly, the centre of a spectacle lens is that part of the lens through which a normal ray of light passes without deviation.

It may also perhaps be as well to define one or two other terms of which I have made use in the course of this paper. In passing through any part of a spherical or cylindrical lens other than the centre, light is bent out of its course. This bending quality of a lens is alluded to as *prismatic effect*; and the alteration in the course of the ray of light is referred to as its *deviation*. There is another aspect of the same fact which requires its special word. If an object is looked at through the edge of a lens its apparent position is altered. This alteration in the apparent position of an object I call *displacement*. So that there are these three terms, prismatic effect, deviation and displacement, which are all different aspects of the same thing; prismatic effect referring to the quality of the lens, deviation to the effect on the light, and displacement to the apparent effect on the object. I may also note that in dealing with an oblique displacement, or a deviation in an oblique direction, I have generally found it convenient to resolve the obliquity into its horizontal and vertical elements. This is particularly useful in treating of spectacle lenses, as there is so much difference between the action of the muscles which control the horizontal movements of the eyes and those which control their vertical movements.

Let us take some ordinary spectacle lenses to illustrate our definition of the centre.

Fig. 1 represents a convex spherical lens with vertical and horizontal sections. It is clear from the shape of the horizontal section that all light passing through it must be bent either to the right or to the

FIG. 1.

left, except in the thickest part where tangent lines would be parallel. And this would be true whether the section were made through the middle or above or below it. In respect, then, of horizontal deviation, we can see that the vertical line on the plan represents the position of no deviation. Similarly if we look at the vertical section we shall

FIG. 2.

see that the locus of no up or down deviation is the horizontal line. It is clear then that if the vertical line represents that part of the lens where there is no lateral deviation, and the horizontal line represents that part where there is no up or down deviation, the only part of the lens where there is no deviation at all is the point where these two lines cross. That is the centre of the lens.

Let us take the case of a plane cylinder. Fig. 2 shows such a lens

with a vertical axis. This is much simpler, because it is evident there is no up and down deviation, and the place of no deviation is the apex of the cylindrical curve, which is represented by the vertical line in the figure. Here, then, the centre is not a point but a line.

And let us note, for this is important, that the centre is a vertical line only when the axis of the cylindrical curve is vertical. But when that is oblique, then the centre of the lens is also an oblique line.

Let us see how this oblique axis affects the lines of no deviation when the cylinder is combined with a spherical lens. Take a lens sph. + 2.00 cyl. + 2.00 ax. 45°. We have seen that so far as the

FIG. 3.

spherical lens is concerned, the lines of no horizontal and vertical deviation are represented respectively by the vertical and horizontal lines; also that so far as the cylindrical lens is concerned the line of no deviation coincides with the principal axis of the cylinder. The upper oval in fig. 3 shows these lines and the arrow heads indicate the directions of the displacements caused by the spherical and the cylindrical curves. It is clear that in parts of the lens the displacements or the deviations due to the two components of the lens are in the same direction, and the deviation is therefore increased; but in

others the two lenses act in opposition, and the deviations are therefore neutralised. The result is shown in the lower oval of fig. 3. The locus of no horizontal deviation is a line lying between the vertical line and the axis of the cylinder, represented by the line A B ; and the locus of no vertical deviation lies between the horizontal line and the axis of the cylinder, and is shown as the line C D in the figure. The centre of the whole lens is the point of intersection of the two lines, but it is important for the due appreciation of certain problems connected with spectacles to recollect the condition of lateral and vertical deviation in other parts of the lens.

Fig. 4 shows another lens sph. + 2.00 cyl. - 3.00 ax. 60° . Here the cylindrical displacement is in the reverse direction, *i.e.*, towards the axis. The locus of no horizontal deviation is found on the other

FIG. 4.

side of the cylinder axis. Its position may be best estimated by resolving the oblique 3 diopter deviation into a 2 diopter horizontal and a 1 diopter vertical deviation. This is accurate enough for our purpose, as the axis is 60° , though not quite exact. Then the line of no vertical deviation will coincide with the minor axis of the oval, along which the normals to the cylinder axis and the major axis of the oval are in the ratio of 1 : 2. But we need not puzzle too much over these diagrams, because, as I intend to show you shortly, these lines of no deviation are easily found empirically, and with quite sufficient accuracy for spectacle work.

Having now illustrated what I mean by the centre of a spectacle lens, I want to direct your attention to the consideration of spectacle lenses taken in pairs. I suppose we all of us, when talking loosely, use some such phrase as "the eye should look through the centres of the lenses." The words convey the idea, perhaps, with sufficient accuracy for most purposes, of what we ought to aim at in spectacle fitting.

But clearly it is not an exact expression. The eyes range over the whole of the lenses ; and it would be more precise to say that spectacles should be so arranged that the eyes look through corresponding parts of the lenses, where the displacement, due to prismatic effect, is equal and in the same direction. Now, it is evident that these conditions are only possible when the two lenses are of equal power, and, in the case of cylinders, in a similar position. When we come to consider the rule as applied to most cases of oblique astigmatism, or to cases of anisometropia, we are met with a difficulty.

FIG. 5.

Let us take a simple case of oblique astigmatism. A pair of spectacles, as represented in the top diagram of fig. 5, is fitted with lenses

R. cyl. + 1.00 axis 60°

L. cyl. + 1.00 axis 120°

If you look at the diagram you will see at once the difficulty that arises. The straight lines represent in each eye the centre of the lens, or that part of the lens where there is no prismatic effect. The arrow heads show the direction of displacement, due in each lens to its cylindrical curve. There is only one possible position where displacement is equal and in the same direction, viz : when the eyes look through the geometrical centre. If they look above, the centres are too narrow ; if below, the centres are too wide ; if they look to the right, the displacement of the right eye is obliquely upward, of the left obliquely downward ; if they look to the left, the displacement of the right lens is obliquely downward, that of the left lens obliquely upward.

It is important to note that this displacement increases as the part of the lens through which the eyes look is further from the centre; and that its rate of increase is greater the deeper the curves of the lens.

We can examine this better in dealing with our next case, a case of anisometropic myopia. Let us take the spectacles as

R. sph. — 2·00

L. sph. — 6·00

the diagram shows the spectacles in horizontal section and in plan. Here again you will see that the only part of the lenses when the displacement is equal is in the geometrical centres; for there in both lenses the displacement is = 0. Now I want you to see that in the weaker lens the prismatic formation to which the displacement is due is much less marked than in the stronger one; and also that while near the centre

FIG. 6.

The prismatic effect is slight, as we approach the margin it becomes much more marked. If we take four distances, 5, 10, 15 and 20 millimeters from the centres of the lenses, which distances are represented by the circles, we shall find that for the — 2·00 lens the prismatic effect

at 5 mm = 35'
 10 „ = 1°9'
 15 „ = 1°43'
 20 „ = 2°18'

while for the — 6·00 lens it is

at 5 mm = 1°43'
 10 „ = 3°26'
 15 „ = 5°9'
 20 „ = 6°51'

So that if the eyes be directed 5 mm. to the right, there is a deviation of the right line of sight of $35'$, and of the left of $1^{\circ}43'$; while the respective deviations for the right and left lenses at a distance of 20 mm. from the centres are $2^{\circ}18'$ and $6^{\circ}51'$.

What is the remedy for this? Clearly there is no complete remedy. I have said elsewhere spectacles are always a compromise. Every possible pair of spectacles presents certain insurmountable difficulties. But mitigations are possible; and it is not the least fascinating part of the craft of the Spectaclemaker to discover and apply these mitigations.

In the first place much may be done by judicious decentring. I hope later on to deal with some of the principles which may safely guide us. But look for a minute again at fig. 5, and see what decentring will do for us here. As it is you will recollect that throughout the upper halves of the lenses the centres are too narrow, and in the lower halves too wide. Now, suppose we decentre each lens 1 cm. inwards, as in the lower diagram. The centres are now nowhere too wide. In parts certainly they are too narrow; but that, as I will explain later, is a lesser evil. That is an instance of what can be done by decentring.

Another method of mitigating the bad effects of unequal displacements is by using small glasses; preferably shallow shapes; *e.g.*, ovals with a short minor axis, or ovals with the top half cut off. By this means you abolish the greater differences of prismatic effect at the margins; and especially by the shallow shapes you reduce them in the direction where they are least tolerated. In this connection I would call your attention to the value of Franklin and bifocal spectacles, in which the lenses must necessarily assume this shallow shape. There are many different ways of combining the two lenses in Franklin spectacles, and they are all equally suitable to this purpose with one exception. I make an exception of the worked bifocal, where the two lenses are ground on the same piece of glass. This form of bifocal should never be used in cases of anisometropia such as we are considering, because it is impossible to work the glass with the centres in the middle of the lenses. The lenses are therefore what we may call marginal, and the differences of vertical prismatic effect are increased. Of course these objections only apply to the special cases we are considering. In some cases the worked bifocal may be the best form of Franklin lens.

For the same reason care should be exercised in fitting cemented

bifocals that the added lens is so centred and set as to neutralise the vertical prismatic effect due to its position on the margin of the large lens. This requires careful calculation and adjustment, and unless it is done the cemented bifocal is as unsuitable for these cases as the worked bifocal.

Of the many forms of Franklin spectacles, I myself give preference to the two separate lenses with a straight division between them; largely for the reason that there is then no difficulty in arranging the centre in the middle of the verticle axis of each lens. Another advantage that attaches to this form is that it facilitates a difference in the width between the centres of the upper and lower halves; we shall see later on that this is generally desirable. I may add that a further point in its favour is that it permits the tilting of the lower lenses, which is a very important advantage, though the reason why it is so does not come properly into the present paper.

Now I want to take you back again (see fig. 6) to the case of anisometropia, where the correction was

R sph. — 2·00

L sph. — 6·00

I called your attention before to the great difficulty that is involved in a pair of spectacles fitted with such lenses. The basis of the difficulty is the desire of the eyes to fuse the two images which they receive. This fusion occurs only when the images fall upon corresponding parts of the retina. The efforts of irregular convergence which the eyes make in order to ensure this effect are involuntary; they cannot be controlled; and in looking through spectacles such as these, these irregular efforts must be constantly exercised in all directions. For instance, as the eyes range from the centre upwards, they pass first through an area, where the difference of displacement is very slight, and can be corrected perhaps with little inconvenience; at a distance of 10 mm. from the centre the difference of displacement is equal to that which would result if a prism of $2^{\circ} 17'$ were held base up in front of the left eye. At 15 mm. the difference of prismatic effect is $= 3\frac{1}{2}^{\circ}$; strong eyes can still perhaps fuse the images, but the strain is so great that after a few seconds the muscles are over-tired and give way, with a result that the images separate. At 20 mm. fusion is no longer possible and diplopia supervenes. So much for one direction. It will be seen that if the eyes range down instead of up, the same efforts are necessary but in an opposite direction; while if they travel to the right they must unduly diverge,

and if to the left, converge. Thus the whole gamut of strain is sounded, and the extreme effort of every muscle is more than demanded. I have been led to enlarge upon this subject, because I regard it as one of the most difficult problems with which we Spectacle-makers are confronted. Many suggestions have been made for the treatment of these cases. Evidently the treatment must depend on considerations of the age, health and habits of the spectacle wearer; on the existence or non-existence of binocular impression, and so on; considerations which are certainly not germane to the subject of the present paper, and which, moreover, in my view, lie outside the proper province of the Optician.

But I want to call your attention to a suggestion which I made some five years ago for treating such cases with what I have called concentric bifocals. I have already pointed out that the greater prismatic differences exist only in those parts of the lenses which are further removed from the centres. My proposal is to reduce the size of the stronger glass in myopia, or the weaker in hyperopia, so that

FIG. 7.

the difference in prismatic effect of the extreme margin of the reduced lens and the corresponding part of the other lens does not exceed what can easily be corrected. Upon the remaining surface of the bifocal lens I propose to work the curve of the other lens.

The figure which illustrates our case of anisometropia treated in this way explains my suggestion better than words. With spectacles so arranged, each eye being fully corrected, easy binocular sight is obtained through the central and effective part of the lenses; and if the sight is directed through the marginal part of the lenses, there is at least no strain from difference of prismatic effect; both images,

though only one is clear, falling naturally on corresponding parts of the retina.

This method has been tried and adopted with success by several Oculists, and I venture to commend it to those of you who are bold enough to do your own refraction, as a safe way of dealing with these difficult cases.

As some relaxation before entering upon the second part of my paper, the effect of centring upon the conjugate movements of the eyes, I propose to demonstrate the different methods of finding and marking the centres of spectacle lenses.

1. By reflection.
2. By finding points of no horizontal, and of no vertical deviation.
3. The Maddox analyser.
4. The Dixey Prismeter.
5. A new centring instrument.

Perhaps it may be asked, why it is necessary to be so minutely particular about the centring of spectacle lenses. The eyes have an extensive power of adaptation, and so long as a rough accuracy is attained, will adjust themselves to any slight difference of displacement. And the answer is, that in these minute differences of displacement are often involved the whole difference between comfort and discomfort, between ease and pain, between a beneficial and an injurious effect of the spectacle lenses upon the eyes. And what especially makes the matter worth studying is that in some directions a wide difference of displacement is allowable, and, indeed (as we shall see) desirable; while in other directions a very small difference of deviations is attended with pain and distress.

Now in approaching the consideration of the pathological aspect of the conjugate movements of the eyes, we trench on difficult ground. I cannot leave it out of account in dealing with the centring of spectacle lenses; but I will say frankly that in many of the problems connected with the subject I have no conviction, nor have I the knowledge which I should consider necessary before giving a trustworthy opinion.

In such a case one generally turns to authority; but the authorities on this subject are notably barren. You will find in the text books plenty about normal movements, and something about abnormal movements, but, so far as I can discover, there is very little about the pathology of abnormal movements, as distinguished from morbid con-

ditions. Nevertheless, there are certain propositions, I mean to lay four before you, which, based as they mainly are on common sense and common experience, I think we may conditionally accept as guides in our practical work of spectacle fitting.

But before I attempt to formulate these more or less debateable propositions, let us examine two or three points connected with the conjugate movements of the eyes which are merely matters of demonstration. Let us consider the conditions of normal convergence.

FIG. 8.

Starting with the eyes at what we may call the position of rest : both eyes are directed to a point at infinite distance, the visual lines are parallel, and remain so, as the eyes turn about in their sockets ; but only so long as the objects looked at are at an infinite distance ; if a near object is looked at, the eyes turn inwards, and the lines of sight converge. We have this represented in fig. 8.

OO' represent the centres of rotation of the two eyes. The parallel lines OA $O'A'$ represent visual lines when the object is at infinity. B

is a near point at short reading distance, a quarter of a meter, to which the eyes converge along the lines OB O'B'. We will take pupil distance at 60 mm.; then we have

$$AB = 30 \text{ mm.}$$

$$OA = 250 \text{ mm.}$$

and $\tan \phi$, the angle through which each eye turns in converging,

$$\begin{aligned} & \frac{30}{250} = .12. \\ \text{or, } \phi &= 7^\circ. \end{aligned}$$

It is evident then that each eye turns through an angle of 7° in converging to an object at ordinary reading distance. This is our first point, and is simply a quantitative statement of the normal exercise of the function of convergence.

The second point to which I would call your attention is illustrated by the same figure:—In converging sight the distance between corresponding points on the visual lines varies inversely as their distance from the centres of rotation of the eyes.

This is a matter of great importance in its application to spectacle fitting. Spectacles that are arranged for use at a definite distance, as for reading, should always be centred with this condition of the visual lines in view; and it will be interesting on this account to arrive at some quantitative estimate of the amount of decentration required. The point S on the figure represents the position of the spectacle lens in front of the eye. Unfortunately, the distance of S from O cannot be measured. I take it in an average case as 20 mm. It must always be estimated. In extreme myopia it will be greater, in hyperopia, less; long lashes or a particular formation of the nose may increase it. But taking OS as 20 mm., we have

$$\begin{aligned} ST &= 20 \tan \phi \\ &= 20 \times .12 = 2.4 \end{aligned}$$

which gives us 4.8 mm. as the difference in centering between distance and reading spectacles. It is easy to confirm these figures with the aid of what I call my gamma measure, which you will find on the table, and which anyone can make for himself. It consists of two discs with pinhole apertures pivotted together in such a way that the distance between the apertures is variable. Fixing the eyes on a distant object, hold the measure in the position of spectacles, and adjust the width till the two apertures appear to coincide; measure the

distance between them ; then repeat the experiment with the object at reading distance : and the figures will be verified.

We may, therefore, take it as an established rule for spectacle fitting that the centres of reading spectacles should be about 5 mm. narrower than the pupil centres when the eyes are fixed at distance ; *e.g.*, if the pupil distance is measured as 60 mm., the reading spectacles should be centred 55 mm.

Now I want to call your attention to the next point, that centres can only be absolutely correct when spectacles are used at a definite distance. With spectacles for general use, as the eyes turn from one object to another, ranging over distances of from 6 ins. or so to infinity, the centres of the spectacles should also vary from 50 to 60 mm. For each distance between reading distance and infinity there is a corresponding value for the spectacles centres lying between 60 and 55 mm. Clearly spectacle lenses cannot be made to correspond with these differences. We must either centre the lens for distance, and be content to have them too wide for reading ; or we must centre them for reading, and have them too narrow for distance ; or we must find a mean. The consideration of this problem forces us on to the more difficult ground of the pathology of convergence.

I have said that I mean to submit to you four propositions, which, in my opinion, may be accepted as safe guides in our practice of spectacle fitting ; and my first proposition is that *wherever possible the normal relation between convergence and accommodation is to be maintained.*

To illustrate the application of this rule let us take a simple case of presbyopia, represented by the formula R and L sph. + 1.00. Now, in this case, before the intervention of presbyopia, normal relations between convergence and accommodation have prevailed. With the 7° of convergence necessary for reading has been exercised an accommodation of 4 diopters. But so soon as you give the + 1 spectacles, you reduce the necessary accommodative effort to 3 diopters. This degree of accommodation has previously been associated with a convergence of not 7° but 5½°. The spectacles should, therefore, be so centred that the convergence at 250 mm. is reduced by 1½°. With convex lenses this means a decentring inwards in addition to the similar decentring due to the position of the spectacles on the visual lines. With concave lenses the allowance takes the form of an outward decentring, and it will be seen that it occurs in an opposite direction to the allowance for position on the visual lines, which it may

either exactly neutralise, or over or under neutralise, according to the strength of the lens.

In cases of hyperopia and myopia when the same strength of lens is used for two distances, normal relation of convergence and accommodation may be maintained by the use of what I have called bicentric spectacles; *i.e.* spectacles, each eye of which consists of two lenses as in bifocals, but with each lens so centred that among other things allowance is made for convergence.

I suggest this as a general rule, but it must be applied with discretion, as it is evidently subject to modification. In the case of an adult with a slight error of refraction, who has not habitually worn spectacles, it is clear that habit will have interfered with the normal relation between convergence and accommodation. Take the case of a myope of 2 diopters. He will have the habit of converging up to half a meter without exercise of his accommodation, and for reading at 250 mm., he will only require 2 diopters. Similarly a hyperope will accommodate without converging, and will require more than 4 diopters of accommodation in converging to 250 mm. In such cases a modification of the rule may be allowed, but how far this concession to habit should extend, or whether an effort should not be made to restore normal relations, are precisely questions on which I have no conviction. They may be further considered in connection with my third proposition.

My next proposition is that *artificial convergence induces accommodation*. There is no doubt of the converse, and in view of the close inter-relation of the two functions, it seems possible to assume that either may be stimulated by the other. Whether this is so or not, our practice in centring spectacle lenses is not materially affected, because if the assumption is right, it would only confirm the rule, which may be briefly indicated as "convex in and concave out," for which we have already ample reasons; and if it is not right, it need not be considered, and our other reasons are not affected. But if we may assume that this proposition is correct, we can claim for the judicious application of the rule to the centring of spectacles an importance of great weight. It will be admitted that among the therapeutic properties of spectacles, one of the chief is to limit undue accommodation. It is clear that, if our proposition holds, by reducing convergence we tend to check undue accommodation. Thus the practice we advocate for other reasons acquires additional value from the therapeutic point of view.

There remain two propositions which deal respectively with dissimilar deviations in a horizontal and in a vertical direction; and my third proposition dealing with horizontal deviations is that *slight divergence is not painful or injurious, but excess of convergence is injurious and to be avoided*. I can give you no reasons without getting beyond my depth. But I do not think that the proposition will be questioned by anyone with practical experience. I have already demonstrated the extent of normal convergence, which amounts to 14° taking the two eyes together at an ordinary reading distance; and on the point of the injurious effect of excessive convergence authority speaks very clearly. Slight divergence may I think safely be defined as 1° for each eye. I do not think this should be exceeded unless the nature of the lens demand it. Referring back then to the problem which I left unanswered, how to centre lenses which are intended for general use; we are in a position to lay down that the lines of sight must never at a working distance pass through the diverging parts of the lens, *i.e.*, through both nasal sides, of convex, or both temporal sides of concave lenses, while, if the nature of the lenses demand it, the lenses may be so centred that for distant sight the visual lines *may* pass through the converging parts of the lenses, provided always that the prismatic effect does not exceed 1° for each eye. This you will see is a further confirmation of our rule, convex in, concave out.

The fourth and last proposition on the subject of conjugate movements is that *difference of vertical deviations is painful, and injurious; and is by all possible means to be avoided*. This again is a proposition which will assuredly not be questioned by anyone with experience, and in its application to spectacle work, is of the first importance. When the lenses allow, the centres should be set with the nicest accuracy, so that vertical displacements are similar in corresponding parts of the lenses. Frames should be designed so as to sit straight, as it is evident that with nearly all lenses the slightest degree of obliquity in the position of spectacles or eyeglasses will cause difference in the vertical deviations. In those cases where the nature of the lenses prevents similarity of vertical deviation, every possible means should be adopted for limiting the differences. I have already made certain suggestions in this respects, and others will be found in the text books.

In considering these problems connected with the conjugate movements of the eyes it has been my endeavour to confine myself to that part of the subject which is associated with the centring of spectacle lenses.

Questions of muscular insufficiency, all the phorias and the tropias lie outside the subject of the paper as I conceive it. Nor have I any object but to put before you, as clearly and exactly as I can, those qualities of lenses, and those conditions of the conjugate movements of the eyes, which should be, and indeed more or less must be, in our minds whenever we sit down to consider where we shall put the centres of our spectacle lenses. This clearly lies within the province of the Optician. But we must distinguish between these necessary and desirable adjustments of the centres, and adjustments that may be said to involve treatment. As I have tried to emphasise ; whatever general rules we make, in adapting them to individual cases there are many considerations involved, the right decision of which demands medical knowledge and experience. I think we Opticians will best fulfil our functions if we confine ourselves to suggesting the possibilities of lenses in their different forms and adjustment, and, so far as our practical work goes, if we limit ourselves to the observance of the obvious conditions which it has been the object of this paper to indicate.