equal periods. In the above tests the rate of flicker was about nine cycles per second.

Summary

(1) An investigation was made on the effect of illumination on visual acuity (*a*) where the test objects subtended only a small angle and were viewed for a prolonged period, and (*b*) where the test objects subtended a considerable angle but were viewed for only a fraction of a second.

(2) By these methods we investigated the effect of intensity of illumination on visual acuity, (*a*) for normal sighted observers, (*b*) for normal sighted observers given defective vision by means of glasses, and (*c*) for observers with abnormal vision. In each case we found a clearly marked increase in visual acuity as the illumination was increased up to about 100 foot-candles. Beyond this intensity no further increase could be found.

(3) The range 1-100 foot-candles covers that ordinarily met with in artificial illumination. An increase in the intensity from 1 to 100 causes only a twofold increase in visual acuity.

(4) Artificial illumination of 2-4 foot-candles is most probably fully adequate for a variety of purposes.

For very fine work on the other hand, where the maximum visual acuity is required, an intensity of 100 foot-candles should be found adequate.

THE BEARING OF STEREOSCOPES ON THE RELATION BETWEEN CONVERGENCE AND ACCOMMODATION

BY

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WHEN we look into any kind of stereoscope, how is the relation between our accommodation and convergence affected? Does the instrument enforce a squint during its use and, if so, of what kind, and how much? And what is the effect of pushing the pictures further away or drawing them nearer? Since stereoscopes are often used for muscle training, a study of this overlooked subject may be useful.

Our natural thought is that to push the pictures away lessens relative convergence and that to draw them up increases it. We shall see that exactly the reverse is the case, and that the effect of pushing the pictures away is to create relative convergence (artificial esotropia), while the act of drawing them up creates the opposite condition of relative divergence (artificial exotropia). It is all a question of relativity, actual lessening of convergence being accompanied by still greater lessening of accommodation; and actual increase of convergence being accompanied by still greater increase of accommodation.

Before proceeding to prove this it is necessary to consider that no stereoscope can quite reproduce the conditions of Nature, since it cannot make accommodation and convergence increase and diminish strictly *pari passu*. In a stereoscope, while we look at a

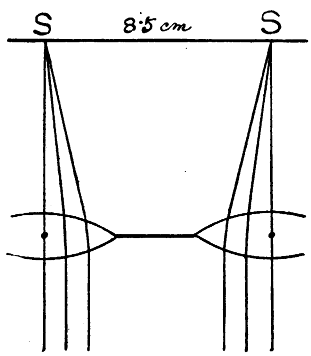

FIG. I.

The stereograms (SS) are in the focal plane, so that parallel light emerges from the lenses, making the distance between the pupils immaterial.

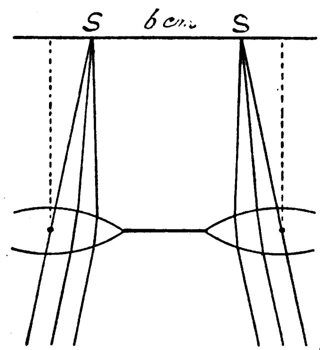

FIG 2.

The stereograms are in the focal plane but, being less far apart than the lenses, induce esotropia.

stationary stereogram, accommodation remains practically unchanged, though convergence is continually varying, from its minimum when we look at the background of the picture to its maximum when we look at the foreground.

When convergence is spoken of in this paper it may be defined as that present when we fuse mid-distance corresponding objects in the two pictures. These, therefore, form the object points for our calculations.

The simplest case to understand is when the pictures lie in the *focal plane* (*i.e.*, in the principal focus) of the lenses. Accommodation is then necessarily nil, for parallel rays enter the eyes. Is convergence also nil? Not necessarily. It is only so when the separation of the pictures is just equal to the separation of the optical centres of the lenses as in Fig. 1. Generally, as in Fig. 2, the separation of the pictures is much less than this, enforcing in consequence a convergent squint. Take, for example, a Holmes stereoscope, in which the optical centres of the lenses are 8.5 cm. apart. Nearly all the stereograms we employ are closer together than this, a favourite separation being 6 cm., in which case it is evident that, as in Fig. 2, the visual lines must converge considerably, and indeed a simple calculation shows that there is an inward squint of about 13 prism-dioptres (or "tangent centunes" as we might perhaps call them, since Prentice's unit is useful apart from prisms). This is one reason why normal observers feel inclined to draw the pictures up nearer than the focal plane. It is to lessen the uncomfortable squint. The active accommodation induced by this proceeding, however, has the disadvantage of making a distant scene appear less remote. To give the greatest sense of distance, stereograms which depict distant scenes should be as wide apart as the optical centres of the lenses; the pictures can then be regarded in the focal plane with comfort, both accommodation and convergence being at zero, as in Fig. 1. For strengthening the fusion power of sportsmen and aviators, such wide pictures are specially to be recommended.

For training squinters, needs differ, and I have drawn up the following table, the sign of a convergent squint being plus, and of a divergent minus.

Each figure in the middle row is calculated as the product of the dioptric power of the lenses and the difference (in centimetres) between the lens breadths and the picture breadths. Denoting the lens breadth by l and the picture breadth by s the equation reads*

$$n\,\%^{t}\,(n\Delta) = D.\,(l - s).$$

At the focal distance of a Holmes Stereoscope

Breadth of stereogram (in cm.) ...	10	9.5	9	8.5	8	7.5	7	6.5	6
*Artificial squint (tangent centunes)	-8 %	$-5\frac{1}{4}$%	$-2\frac{1}{2}$%	—	$+2\frac{1}{2}$%	+5%	+8%	$+10\frac{1}{2}$%	+13%
Artificial squint in deg. of arc ...	$4\frac{1}{2}$°	3°	$1\frac{1}{2}$°	—	$1\frac{1}{2}$°	3°	$4\frac{1}{2}$°	6°	$7\frac{1}{2}$°
	5.5	5	4.5	4	3.5	3	2.5	2	
	$+15\frac{3}{4}$%	$+18\frac{1}{2}$%	+21%	$+23\frac{1}{2}$%	+26%	+29%	$+31\frac{1}{2}$%	+34%	
	9°	$10\frac{1}{2}$°	12°	$13\frac{1}{2}$°	15°	$16\frac{1}{2}$°	$18\frac{1}{2}$°	$19\frac{1}{2}$°	

*Unless otherwise specified, % is assumed to be always measured on the tangent.

To give a practical example of the use of the table. A recently operated squint has a residuum, let us say, of +18 per cent. (*i.e.*,

*Since tangent quantities are not suitable for multiplication, a very slightly more accurate formula would be 2 tan $\frac{-1\,D}{2}$ $(l - s)$ giving the result in degrees of arc.

18 tangent centunes of convergence) or 10° of arc. We look up the nearest figure to 18 per cent. in the middle row, or to 10° in the bottom row, of the table and find it under 5 cm. A stereogram of this marked breadth should therefore be selected and placed in the focal plane. The patient would then, while wearing his full correction, be in a position for easiest fusion of the pictures. This fusion should be well cultivated by other stereograms, and then each be slowly and steadily drawn up (preferably by means of a long endless screw under the longitudinal strip, operating on the cross carrier) for exercise. When the training has advanced sufficiently by this means, a wider stereogram can be conquered by again starting in the focal plane.

Before leaving the focal plane position of the stereogram, we may notice another interesting feature which it presents, that owing to the parallelism of the emergent beams, as in Figs. 1 and 2, neither the interocular distance, nor that of the eyes from the lenses, has any effect upon either convergence or accommodation. The moment, however, the stereogram is moved away from the focal plane, the case is complicated by variables, for we have now to take account both of the interocular distance which varies with different persons, and of that of the eyes from the lenses, which also differs with different observers and instruments, and even with the same observers at different times. Before showing how to calculate for these measurements, it will, I think, suit the clinical reader best to tackle first an easier problem, which avoids all variables. It consists in determining under what conditions accommodation and convergence are *equal*. I find that the distance of any stereogram from the lenses necessary to make accommodation equal convergence is an easily ascertained multiple of the separation of the pictures from each other. The following general statement is offered as applicable to stereoscopes of all sizes and shapes.

RULE. *Accommodation and convergence agree whenever the ratio between the distance of the stereogram from the lenses and the separation of its pictures is the same as the ratio between the focal length of the lenses and the separation of their optical centres.* If u, s, f, and l denote these four items, $A=C$ when $u/s=f/l$ (or, dioptrically expressed, $sD_1=lD$).

When the lenses of a stereoscope are fixed their focal length *divided* by their separation (or equally their dioptric power, *multiplied* by their separation), is a constant for that instrument, and is the amount by which we have to multiply the separation of the pictures in order to find their neutral distance from the lenses. For example, lenses of 12 cm. focal length, and separated by 6 cm., would require any stereogram to be placed ($12 \div 6 = 2$) twice as far from the lenses as the pictures are separated from each other.

The lenses of a Holmes stereoscope have a focal length of about 19 cm. and a separation of 8.5 cm. Therefore, the ratio for that instrument is $19 \div 8.5 = 2.24$. The neutral distance for any stereogram, therefore, will be 2.24 times its own breadth. On this principle I have graduated the longitudinal strip of the Holmes with a series of cross lines, each marked with the breadth of the stereogram of which it indicates the neutral position. Thus, for example, $A = C$ when a 6 cm. stereogram is placed on the line marked 6 cm., or when an 8 cm. stereogram is placed on the line marked 8 cm., and this is true irrespective of what the inter-ocular distance, or that of the eyes from the lenses, may be. Any stereogram when pushed beyond its cross line causes steadily increasing relative convergence, and when drawn up from it causes steadily increasing relative divergence. It will be evident at once that in the treatment of phorias the pictures should play only on the proper side of their cross line and be pushed in the proper direction. An easily remembered rule may be given. *For exo's travel outwards, for eso's inwards.* For a tropia, the same direction of movement holds good, but the starting point has to be different, since it is evident that if the pictures could be fused at the $A = C$ distance, it would not be a case of tropia. We have to make a concession by trespassing on the easy side of the $A = C$ line (beyond it for a convergent squint, and within it for a divergent) until fusion is obtained, and then very gradually work in the training direction. It must be confessed, however, that for pronounced squints, Worth's amblyoscope is more suitable than a stereoscope. For phorias, on the other hand, stereoscopes are more interesting, more varied, and contribute more definitely gradual treatment.

Let us now see how to prove the ratio rule for the neutral distances. We make use for this purpose of the self-evident conception that convergence equals accommodation whenever the visual lines intersect at the point accommodated for. This is physiologically true, in spite of the base-line of accommodation being in advance of the base-line for convergence. If we cling to this simple conception, we have only to arrange the distance at which any stereogram must be placed to make the virtual images of the two mid-points coincide actually (not merely subjectively by fusion) in the median plane. Then each visual line is instinctively directed towards the image proper to it, and for which accommodation also takes place, and since the images coincide, the visual lines intersect at the point accommodated for, quite irrespective of the breadth or distance of the eyes.

In Fig. 3 are seen two similar triangles (ILL and ISS), of which the base (l) of the larger represents the interlenticular, and the base (s) of the smaller, the interstereoscopic separation, the common

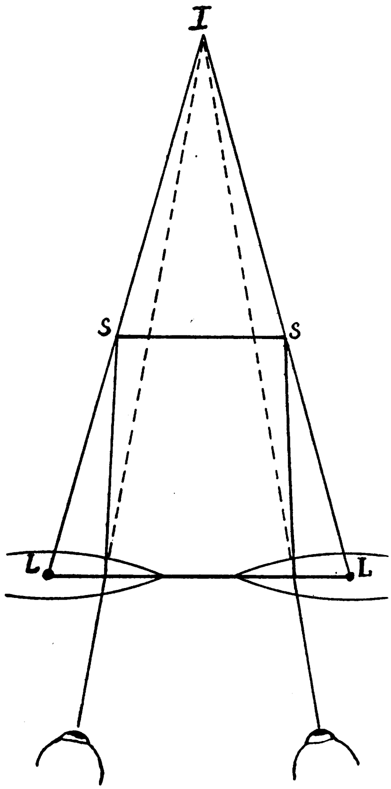

FIG. 3.

When the virtual images (I) coincide in the median plane, the visual lines intersect at the point accommodated for, irrespective of the pupillary separation or the aloofness of the eye.

apex (I) being the site of the two combined virtual images of the object points SS. The distance between the two bases is the object distance, which we may call u, while the entire height of the larger triangle is the image distance, which we will call v. Therefore, the height of the smaller triangle is $v-u$. Now the triangles being similar, their heights and sides are proportional to their bases and therefore—

$$(v - u)/v = s/l$$

But, by optics, $v = uf\ (f - u)$.

Substituting this value for v, and simplifying,

$$u/s = f/l.$$

or, in words, the required ratio between the distance of the pictures from the lenses (u), and their separation from each other (s), is a constant found by dividing the focal length of the lenses by their separation. This confirms the rule given above. It will be noticed that accommodation and convergence are both measured by the reciprocals of the same line (measured in terms of the metre) so that they must be equal, no matter how much the line is elongated or contracted.

The way to graduate the longitudinal strip of a Holmes stereoscope is to make the first cross line at the focal length of the lenses and mark it 8.5 cm., then make the other cross lines 11.2 mm. apart, marked 8 cm., 7.5 cm., and so on, towards the lenses, the same series being continued also beyond the focal length.

Let us see how the same principle applies to those stereoscopes which are provided with lenses which are capable of approximation or recession from each other. Here, one of the hitherto invariable factors—the distance (l) between the lenses—now becomes variable, so the ratio l/f is no longer a constant.

In one form of instrument, however, the distance of the stereogram is permanently fixed at the focal length. In that, for example, described by Javal, the movable lenses are of +10D. sph. and the pictures 10 cm. away. In this case $u=f$, and therefore $s=l$ when $A=C$. Put in words, accommodation is nil and the visual lines are parallel when the separation of the pictures equals the separation of the lenses, as may be seen from Fig. 1 of this paper. Dr. Wells has elaborated this form of instrument in his phoro-optometer stereoscope, and I might say that I have recommended his excellent set of cards for my patients since they were first published. There appears, however, to be a little oversight in his directions for the use of the instrument, since he makes the starting point take account of the pupillary distance, which we have shown to be immaterial. The true starting point, at which the visual lines are parallel, is when the separation of the cards (not that of the pupils) equals the separation of the lenses.

In yet another type of instrument, the pictures move as well as the lenses, leaving only one quantity invariable, namely, the power of the lenses; but there again, at any moment, the $A=C$ formula ($u/f=s/l$) still holds good.

Dioptrically $D_1 = Dl/s$.

Conclusions

1. If the pictures of a stereogram placed in the focal plane are closer together than the interval between the optical centres of the lenses, they cause forced esotropia.

2. When drawn nearer, this esotropia gradually lessens and becomes nil at a distance from the lenses equal to the interval between the pictures multiplied by a constant. Nearer still, exotropia enters, increasing with every approach.

3. In every fixed stereoscope, this constant can be found by dividing the focal length of the lenses by their optical separation.

In the Holmes stereoscope, the constant is 2.24, so that the neutral distance for any stereogram is 2.24 times its own breadth from the lenses.

4. The longitudinal strip of the Holmes instrument can be graduated in this manner to save calculation, so that a stereogram of any breadth can be at once placed on its neutral seat if required, beyond which Con. $>$ Acc. and within which Con. $<$ Acc.

5. For the training of an esotrope, the widest stereogram should be selected that can be certainly fused at the *far* end of the instrument, and it should be gradually caused to approach. For an exotrope, the narrowest stereogram should be employed that can be fused as *near* to the eyes as accommodation permits, and it should be gradually caused to recede.

A TREATMENT FOR TRAUMATIC SYMBLEPHARON

BY

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IT too frequently happens, after injuries to the lower lids that a symblepharon forms, and this in spite of all treatment.

The injuries are those which chiefly affect industrial workers, such as lime and acid burns, and burns with molten metal. In these cases the conjunctival surface of the lower lid is, in places, often destroyed, and also areas on the bulbar conjunctiva.

I have had to deal with about twelve such cases during the past two years. The primary object of treatment has been to prevent union between the palpebral and bulbar conjunctival surfaces. The free application of ointments, small rolls of lint soaked in vaseline and placed in the conjunctival fornix, and the very frequent drawing apart of the opposed surfaces have been employed, but in spite of these measures, union between the lid and globe has occurred.

In order to overcome this union between lid and globe, I employed the following simple apparatus and have used it with remarkably good results:

A sufficient length of silver wire (53 Stubb's system in thickness) is bent as shown in diagram, the free ends of the wire being soldered to make a continuous framework. It will be seen that the completed framework consists of two horizontal bars connected at each end by a loop. One of these bars fits into the conjunctival fornix, whilst the other lies outside the lid, the two loops crossing over the lid edge.

Minor adjustments will be found necessary in individual cases