

LENS EFFICIENCY—A CLINICAL CONCEPT*†

BY

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NEW YORK

THE fact that a lens has a different effectivity depending upon its position before the eye is well known. We say a convex lens gains in effectivity when moved away from the eye and loses in effectivity when moved closer to the eye. A concave lens behaves in just the opposite way. There is, however, another feature of changes in lens power which is not dependent upon movement farther from or nearer to the eye. This variable lens effect may be called its "efficiency," which may be of an ascending order, termed positive efficiency or of a descending order termed negative efficiency. A similar gradation of efficiency may be postulated with reference to the accommodation.

It is well known that if a natural emmetrope, an uncorrected hypermetrope and an uncorrected myope each accommodate the same amount, they are not all focused for the same distance. But this is also true, though to a less extent, for the corrected hypermetrope and the corrected myope. The prevalent idea that the corrected hypermetrope and the corrected myope accommodate 1.0 D. for one metre, 2.0 D. for 1/2 mm. and so on is not correct.

For example, the natural emmetrope accommodating 3.0 D. is focused for 333 mm. from the eye. But the 2.0 D. corrected hypermetrope and the 2.0 D. corrected myope when accommodating 3.0 dioptres are focused for 360 mm. and 309 mm. respectively. As a corollary of the preceding the uncorrected hypermetrope has to accommodate more and the uncorrected myope has to accommodate less than the emmetrope, for the same distance. But this difference also holds good, though to a less extent, for the *corrected* hypermetrope and the *corrected* myope. The separation of the two elements which together make up the "Lens emmetrope," produces a difference in what may be called accommodative efficiency, using the term not in a physiological sense, but in a purely optical sense, the same as we shall consider in connection with lens efficiency.

Taking the accommodative activity of the natural emmetrope as a standard and calling this normal efficiency, a more efficient activity may be said to have *positive* efficiency, while a less efficient activity may be said to have *negative* efficiency.

* Presented before the New York Academy of Medicine, Section of Ophthalmology, May 21, 1945.

† Received for publication, July 27, 1945.

On this basis the accommodation of the corrected hypermetrope has negative efficiency, because he has to use *more* accommodation than the natural emmetrope for the same distance. The accommodation of the corrected myope has positive efficiency because he has to use *less* accommodation than the natural emmetrope.

In a similar sense the plus lens which replaces the accommodation may be said to have positive or negative efficiency. If a plus lens of less power replaces a given amount of accommodation the lens has positive efficiency. If a plus lens of greater power replaces a given amount of accommodation the lens has negative efficiency.

The efficiency of the replacing lens in different refractive conditions is as follows: In the natural emmetrope it has a negative efficiency. In the corrected myope, it also has negative efficiency, which is even more marked. In the corrected hypermetrope, it may have positive or negative efficiency, depending upon what part of the accommodation it replaces. When it replaces the accommodation used to neutralise in whole or in part the hypermetropia, the lens has positive efficiency. But when it replaces the accommodation used over and above that amount the lens has negative efficiency.

The value of the replacing lens and its efficiency depend upon four factors (1) the kind of ametropia (2) the amount of ametropia (3) the distance between the lens and the eye and (4) the level at which it replaces the accommodation. By this is meant whether it replaces the 1st, 2nd, 3rd or 4th dioptre of accommodation. In all cases the replacing lens or the equivalent lens has its least value when replacing the 1st dioptre of accommodation. Its value constantly increases as it replaces the 2nd, 3rd or 4th dioptre of accommodation. Thus the equivalent lens in natural emmetropia, for replacing the 1st dioptre of accommodation is plus 1.02, but its value for replacing the 4th dioptre of accommodation is plus 1.16.

This increase has its analogue in the physiological phase of the accommodation as it takes more effort to accommodate for the second dioptre than it does for the first dioptre and correspondingly more for the third and fourth dioptre.

The reason for the differences in accommodative efficiency in different eyes, optically considered, lies in the fact that the corrected ametropes has, what may be considered, a different basic accommodative unit from the natural emmetrope. This basic unit depends mainly upon the kind and amount of ametropia. The basic unit of lens power is the dioptre, one dioptre corresponding to a focal distance of 100 cm., 2 D. to a distance of 50 cm., 3 D. to a distance 33.3 cm., and so on. The natural emmetrope whose accommodative efficiency we may use as a standard and call normal has the same 1.0 D. as his basic unit of accommodation. He accommodates 1.0 D. for a distance of 100 cm., 2 D. for a distance of 50 cm.,

3 D. for a distance of 33.3 cm., and so on. But the basic accommodative unit of the corrected ametropes is not 1.0 D. It is always either more or less than 1.0 D. and depends upon three factors. These are (1) the kind of ametropia (2) the amount of ametropia and (3) the position of the correcting lens.

The basic accommodative unit of the corrected hypermetrope is always more than 1.0 D. For example, the basic unit of the 4.0 D. corrected hypermetrope is 1.19 D. and at a distance requiring 4 units of normal accommodation, say, at 25 cm. from the eye, this hypermetrope has to use 4 times his basic unit, *i.e.*, 4×1.19 which means an accommodation of about 4.75 D.

The basic accommodative unit of the corrected myope is always less than 1.0 D. The basic unit of a 4.0 D. corrected myope for example is 0.87 D., that is, $\frac{7}{8}$ of a dioptré. At a distance requiring 4.0 D. of normal accommodation in the natural emmetrope, that is, 25 cm. from the eye, this myope has to use four times his basic unit of a 0.87 D. This shows an accommodative need of only 3.44 D. The difference between the two is about 1.25 D.

One important bearing of these considerations, is in the correction of presbyopia. The condition and degree of presbyopia which may be termed an error of the accommodation cannot be as accurately defined as errors of refraction. But for purely optical reasons and because of variation in accommodative and lens efficiency, we find presbyopic differences which are clinically significant.

A natural emmetrope, a corrected hypermetrope of say 3.0 D. and a corrected myope of, say, 3.0 D. will all be considered equally presbyopic if they each accept the same reading addition for the same distance, say, a plus 2.0, for a distance of 250 mm. from the eye. But if we compare the amount of accommodation each of them has to contribute to focus at 250 mm. we find that they contribute considerably different amounts. The natural emmetrope contributes 2.24 dioptré, the corrected hypermetrope contributes 2.53 dioptré and the corrected myope contributes only 2.0 dioptrés. The corrected hypermetrope has to accommodate about 0.25 D. more and the corrected myope has to accommodate about 0.25 D. less than the natural emmetrope, making the difference between the two a little over 0.50 D. Yet these three are generally considered equally presbyopic because they take the same reading add for the same distance.

If the degree of true presbyopia is measured by the amount of accommodation one can contribute for near focusing, then in our illustration the natural emmetrope is 2.25 D. presbyopic, the corrected hypermetrope is a little more than 2.50 D. presbyopic, while the corrected myope is only 2.0 D. presbyopic.

If the same three individuals each contribute the same amount of accommodation, say, 2.0 dioptrés for a distance of 250 mm., we

may consider them equally presbyopic in the true sense. But we shall find that now they each take a different reading addition. Using the same data as before, we find that the natural emmetrope needs an add of plus 2.26 D.; the corrected hypermetrope needs an add of plus 2.52 D.; the corrected myope needs an add of only plus 2.0 D. So that in the commonly used parlance, and judging by the strength of the reading add the corrected hypermetrope is a half dioptre more presbyopic than the corrected myope.

Lastly, if the same three individuals are equally presbyopic in both senses, in that they each contribute the same amount of accommodation, say, 2.0 D. and they each get the same reading add, say, plus 2.0 D., then they are each focused for a different distance. The natural emmetrope is focused for 265 mm., the corrected hypermetrope for 281 mm., and the corrected myope for 250 mm., all distances measured from the eye.

Most books on visual optics contain a table giving the approximate presbyopic adds for different ages for different distances. But the tables generally do not take into account the differences in lens and accommodative efficiency herewith presented. An understanding of these differing efficiencies will help to explain the many deviations from the tables often encountered in clinical practice.

A similar consideration applies to the methods for determining the amplitude of accommodation in specific cases. The most direct and most commonly used method is to locate the near point of accommodation. Published tables give the average near point for different ages. But it can be seen from the preceding discussion that the location of the near point does not *tell the same story* in the different refractive conditions.

As an example, in the natural emmetrope a near point of 200 mm. from P. of the eye would show 5.0 D. of accommodation. But the same near point in a 3.0 D. corrected hypermetrope or a 3.0 D. corrected myope would show an amplitude of 5.62 D. and 4.47 D. respectively, a difference of more than 1.0 D.

The difference in the value of the basic accommodative unit in different refractive conditions is of special significance in the presbyopic correction of anisometropia. A patient who wears a plus 2.0 D. before one eye and a plus 4.0 D. before the other eye and assuming that these are full and proper corrections can never focus a near object with both eyes at the same time. If the less hypermetropic eye is the dominant eye and sets the pace for the accommodation of both eyes, then, say, for a distance of 250 mm. the more hypermetropic eye is *under-accommodated* by about 0.38 D. If the more hypermetropic eye is the dominant eye and sets the pace for both eyes, then the less hypermetropic eye will be *over-accommodated* by about 0.38 D.

Similar conditions of course are found in unequal myopic corrections. A patient who wears a -2.0 D. before one eye and a -4.0 D.

before the other eye can never focus a near object with both eyes. If the less myopic eye is the dominant eye and sets the pace for the accommodation, then for a distance of 250 mm. the more myopic eye is *over*-accommodated by about 0.26 D. If the more myopic eye sets the pace for the accommodation then the less myopic eye will be *under*-accommodated by about 0.26 D. In other words in either case when one eye is in focus for a near object the other eye is necessarily out of focus. Of course we know that the anisometropic eyes could not both focus a near object before correction. But it is interesting to note that they cannot do so even after correction, though the discrepancy is much less.

When these anisometropes become *partly* presbyopic, not totally presbyopic, in which case we have a special condition, the same add for the two eyes will leave conditions as they were before, *i.e.*, both eyes cannot be in focus for a near object at the same time. But now it is possible to give the patient equally focused vision in both eyes, for any chosen distance. This is accomplished by giving a stronger add to the more hypermetropic eye, or to the less myopic eye, that is, to the eye which has intrinsically less refractive power. The unequal adds will enable both eyes to be in focus at the same time for the distance chosen. This, incidentally, is something which the eyes could not attain in the pre-presbyopic period.

If the eyes are totally presbyopic, then the same add to *both* eyes irrespective of their differing refractive errors will put both eyes in focus for any chosen near distance. In this respect, then, the anisometrope when totally presbyopic is better off than he was before becoming presbyopic.

The cardinal point to note is the existence of a different accommodative unit for each refractive condition. Since in anisometropia, even when corrected, the two eyes have different accommodative units, both eyes can never be in focus for a near object at the same time except in total presbyopia.

For the same reason the corrected astigmatic eye can never focus a near object accurately in both principal meridians, because each principal meridian has its own basic accommodative unit.

Another element which affects lens efficiency for near vision pertains to the form and thickness of the lens used. To mention it very briefly: a given amount of hypermetropia or myopia may be corrected with lenses of different form and thickness, so long as these lenses have the same vertex power, and the lenses are placed the same distance from the cornea. It is, indeed, to provide for this equality of effect for lenses of different form that the vertex dioptre has been adopted. But in near vision, the double convex, plano-convex and meniscus convex of the same vertex power, do not have equal efficiency. For example, a biconvex, a plano-cx, a meniscus-cx, all of which have a vertex power of plus 3.0 D. and all

placed with their back surface at the same distance from the cornea will all have the same effective correction for the hypermetropia. But they will not have the same efficiency in near vision. The D-cx will have the greatest efficiency, the meniscus convex the least efficiency. In a plus 10 D. lens, for focusing at a distance of 30 cm. from the eye, the D-cx will excel the deep meniscus by about 0.75 D. By this is meant that the meniscus convex will require 0.75 D. more accommodation than the double convex.

These investigations show that when we consider the correction of refractive and accommodative anomalies from a strictly optical and mathematical viewpoint we find a number of unexpected discrepancies. Fortunately in most of our work we may consider the common visual errors from a physiological standpoint. As such, the body is provided with compensatory mechanisms for mastering these deviations. Only in cases where the physiological adjustments are inadequate to cope with these discrepancies is a clinical evaluation of them necessary.

Table I will show a few of the points discussed in condensed form. The first column—T.A. shows a true ametropia in the first principal plane of the eye. The second column shows the "Lens" ametropia as measured by the correcting lens. Calculations for lens and accommodative efficiency are based on the lens being 20 mm. from the first principal plane of the eye.

Table I	Distance	A. U. 1m.	50 cm.	33.3 cm.	25 cm.
T. A. at P.	Nat. E.	1.0 D.	2.0 D.	3.0 D.	4.0 D.
1.02 D.H.	1.0 D.H.	1.04	2.08	3.12	4.16
0.98 D.M.	1.0 D.M.	0.96	1.92	2.88	3.84
2.08 D.H.	2.0 D.H.	1.08	2.16	3.25	4.32
1.92 D.M.	2.0 D.M.	0.93	1.86	2.80	3.71
3.19 D.H.	3.0 D.H.	1.13	2.25	3.38	4.50
2.83 D.M.	3.0 D.M.	0.89	1.78	2.68	3.58
4.35 D.H.	4.0 D.H.	1.18	2.36	3.53	4.70
3.70 D.M.	4.0 D.M.	0.86	1.72	2.58	3.45
5.56 D.H.	5.0 D.H.	1.23	2.46	3.69	4.90
4.55 D.M.	5.0 D.M.	0.83	1.66	2.49	3.33
6.80 D.H.	6.0 D.H.	1.28	2.56	3.84	5.11
5.35 D.M.	6.0 D.M.	0.80	1.60	2.40	3.22
L at 20mm.	E. R. L.	+1.02	+2.08	+3.19	+4.35

It is seen that the plus correcting lens has positive efficiency as it takes a lens of less power to correct a greater degree of hypermetropia, thus plus 1.0 for 0.98 D. of true hypermetropia, plus 6.0 for 6.80 of true hypermetropia and so on. The minus lens has negative efficiency as it takes a minus lens of more power to correct a lesser degree of myopia, thus a -1.0 for 1.02 of true myopia, a -6.0 for 5.35 D. of true myopia and so on. In high errors the difference is specially significant. Thus a patient who is corrected with a -30.0 dioptré lens, has a true myopia of only 20.0 dioptrés.

Column 3. A.U. shows the different accommodative units for different refractive conditions. It is seen that the accommodative unit for the corrected hypermetrope is more than 1.0 D. being 1.04 for the 1.0 D. hypermetrope, and increasing until it is 1.28 for the 6.0 D. hypermetrope. Succeeding columns show the amount of accommodation he has to use for different distances. Thus at 25 cm. from the eye where the natural emmetrope has to use 4.0 D. of accommodation he has to use 4 times his unit which amounts to an accommodation of 5.12 D. (column 6). The accommodative unit of the corrected myope is less than 1.0 D. being 0.96 D. for the 1.0 D. myope and diminishing till it is 0.80 for the 6.0 D. myope. At a distance of 25 cm. he has to accommodate 4 times his accommodative unit which amounts to only 3.20 D.

An examination of any one group, say, the 3.0 D. hypermetrope and the 3.0 D. myope (middle of column 3) shows that at 25 cm. the hypermetrope has to accommodate 4.50, while the myope has to accommodate 3.56. If these two individuals are equally presbyopic in the true sense, in that they can each contribute the same amount, say, 2 dioptrés, then the hypermetrope has a deficiency of 2.50 D. while the myope has a deficiency of only 1.56 D. showing the need for different adds. Various combinations of anisometropia and of astigmatism can be made by reference to column 2, and the differing accommodative needs seen in the succeeding columns.

The bottom line shows the value of the equivalent replacing lens, E.R.L., for different conditions and four different distances. It is seen that the same lens replaces *all* the accommodation necessary for any distance. Thus an add of +3.19 (col. 5) replaces all the accommodation necessary for 33.3 cm., whether this be 3.12 of the 1.0 D. hypermetrope or 3.84 of the 6.0 D. hypermetrope, or 2.88 D. of the 1.0 D. myope or 2.40 of the 6.0 D. myope. For this reason in total presbyopia the same replacing lens puts *both* eyes in focus, in spite of widely different refractive conditions. This line also shows that the value of the replacing lens increases (and its efficiency diminishes) as it replaces successive dioptrés or units of accommodation. Thus it takes plus 1.02 to replace the 1st dioptré of accommodation, plus 1.06 (2.08 - 1.02) to replace the 2nd dioptré of accommodation, plus 1.11 (3.19 - 2.08) to replace the 3rd dioptré

of accommodation and plus 1.16 (4.35 - 3.19) to replace the 4th dioptré of accommodation.

To bring out the points presented more fully the distance between the second principal point of the lens and the first principal point of the eye was taken as 20 mm. instead of the usual 15 mm. This somewhat exaggerates the findings.

OPHTHALMIC PROBLEMS AND VISUAL STANDARDS IN INDUSTRY*†

BY

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WITH the expansion of the Industrial Medical Services has come the realization that the industry presents many visual problems which have to be faced and eventually solved. So far, although this country has made no unified attempt to deal with the vision of employees, individual firms have done so. In 1938 the Industrial Welfare Society sent out a questionnaire to its 750 member firms in order to find out whether applicants for employment had to pass eyesight tests and what minimum visual standards were considered necessary. From the replies received from 398 firms, employing about 1,000,000 workers, it was found that most firms do not insist on eyesight tests; and that the many firms who are vision conscious vary in their approach to the problem. Thus while many small firms do not require employees to pass eyesight tests, others representing the same branch of industry insist on them. A large number of firms, having instituted eyesight tests demand a visual standard of 6/6 or 6/9 in each eye, while other firms are satisfied with 6/12 in each eye.

In this paper an attempt is made to elucidate some of the principles which may guide industrial medical officers in the selection of employees for various jobs in industry. There is no doubt that greater efficiency will be achieved in industry if we place the workers in the jobs for which they are best physically fitted. This would eventually be followed by a larger output in production and would in addition ensure the safety of the workers in many branches of industry. However, under present conditions of employment a country wide compulsory medical examination could not be instituted for all workers. Should such an examination be

* Received for publication May 17, 1945.

† Address delivered to the Association of Industrial Medical Officers, March 24, 1945.