AN EVALUATION OF PROXIMAL CONVERGENCE BY THE USE OF INFRA-RED PHOTOGRAPHY

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Abstract

Convergence of the eyes was measured photographically in two situations:
i) in normal illumination, at distances from 50cms to 10cms
ii) in the dark, by use of infra-red photography. The subjects were instructed to hold the target at the above distances and imagine that they were looking at it.
It was demonstrated that the measurements obtained in the light approximated well with the predicted hyperbolic curve, the formula C = 2D being adequate enough to account for 98% of the variability in the measurements.

Measurements in the dark also resulted in this high degree of agreement with the theoretical curve. However, comparison of the measurements taken in the dark with those in the light showed that the convergence response in the absence of visual clues is strong and is frequently in excess of the required convergence. It is suggested that this is due to proximal convergence which may play a greater role in the position of the eyes for near than has been demonstrated previously.

Key words
Proximal convergence, AC/A ratio, infra-red photography.

Introduction

The stimuli to a convergence response have been traditionally described as:

1. Muscle tonus, bringing the eyes from the anatomical positions of rest (i.e. divergence) to the physiological position of rest (approaching parallelism)
2. Laterally displaced similar retinal images, stimulating a corrective fusional vergence reponse
3. Accommodation, stimulating a convergence response. The amount of convergence (in prism dioptres) per dioptre of accommodation is expressed as the AC/A ratio.
4. Knowledge of proximity, stimulating convergence in response to the perceived nearness of an object.

Tonic convergence is usually considered to be constant throughout standard clinical measurements and these measurements usually include dissociation to prevent fusion. Therefore the two variables in the difference between distance and near deviations must be accommodative convergence and proximal convergence.

However, when considering the near deviation, any change is often attributed to the AC/A ratio alone. If the deviation is more convergent for near the AC/A ratio is considered to be high, and low if the deviation is less convergent for near[1]. However, Rubie[2] reports that there appears to be little correlation, in many cases, between the AC/A ratio measured by the gradient method and that predicted by a comparison between distance and near deviations.

This study investigated the position of the eyes when, by the absence of visual clues, a direct stimulus to accommodation is also eliminated. The resulting convergence is considered to be proximal convergence.

Many studies have been made on the AC/A ratio, giving it a value of approximately 3.5 to 4 prism dioptres per dioptre of accommodation[3].

Proximal convergence has received far less investigation, but at least three different ways of measuring it have been described.;

1. By comparison of the AC/A ratio measured by the 'heterophoria' and 'gradient' methods[4,5].

The distance and near deviations are compared to determine any additional convergence for near (heterophoria method). Since this method must include some proximal convergence, that measurement taken at a fixed distance but with accommodation altered by the use of lenses (gradient method) is subtracted to give a measurement of that induced by nearness only. Such studies give a value of proximal convergence of approximately 1△ at one metre.

However, a criticism must be made of this method of determination. It assumes that the effects of accommodative convergence and proximal convergence must be *summative,* i.e. that each stimulus contributes a certain amount of convergence and that the two can be added to give the final convergence measurement.

There are many physiological systems in which two stimuli may act together to produce a common response. However, should each stimulus act individually the sum total of the responses may be in excess of the response if they act together. For example, the eyes make a saccadic movement to the side in response to a combined acoustic and visual stimulus, however the speed and accuracy of this movement will be much the same if only one stimulus was operating. It would seem that proximal convergence should be measured directly to evaluate its effect and *not* by the subtraction of the effect of the AC/A ratio.

2. By comparison of major amblyoscope measurements with the distance prism and cover test measurements. This may be termed instrumental convergence (which cannot be expressed as a unit per unit of distance). This response has been found to be highest in patients with esotropia, but that the method undervalued the near response if compared with that determined by the heterophoria and gradient methods[6].
3. By determining the convergence response when accommodative requirements are eliminated by plus lenses, as described by Schapero and Levy[7]. The authors found that proximal convergence had a value of approximately 3△ at one metre. The response per unit of distance decreased at closer range, being 4.6△ at 33cms.

   It appeared that proximal convergence did not show a linear relationship to the reciprocal of the distance (in metres) as accommodative convergence shows to each unit of accommodation.

   A criticism can also be made of this, and other similar methods in that the relaxation of accommodation through plus lenses is difficult, and has been found to be even less accurate and efficient than accommodation induced by minus lenses[4,8].

The fact that presbyopes do not show an increase in exophoria for near with the onset of presbyopia although their ability to accommodate is reduced, is a well known clinical finding and has been demonstrated by Sheedy and Saladin[9]. They, and others[10] have suggested that this is due to the fact that the presbyope still attempts to accommodate, bringing about the required convergence. However, such an accommodative response would have to be remarkably accurate to give the stable near readings usually found, and such accuracy has been found to be lacking when a blurred image is received[8]. Moreover, presbyopes are normally wearing a near addition so that a clear image is received, giving no accommodative stimulus.

Brienin and Chin[11], by studying the accommodative response in presbyopes, found that their subjects accepted blur and did not make excessive attempts to accommodate.

One could conclude that, if convergence for near is not provided by accommodative convergence, then proximal convergence may play a significant role.

To study the effects of proximal convergence, one should ideally have a situation where all stimuli to accommodation and fusion are absent. One way of achieving this is to evaluate convergence induced by non-visual stimuli, in total darkness. This is possible by the use of infra red photography and was used in the following study.

Method

1. Normal photographs (i.e. in the light) were taken of 16 subjects converging at the specific distances of 50cm, 33.3cm, 25cm, 20cm, 16.6cm, 12.5cm and 10cm. (i.e. 1/2, 1/3, 1/4, 1/5, 1/6, 1/8, 1/10 metres). (See Figure 1) All of the subjects were non presbyopic with bifoveal fixation at each distance.
2. The photographs were enlarged and the interlimbal distance was measured. As each subject was fixing bifoveally it was assumed that such a measurement could be directly related to the known convergence at each particular distance. Because the inter pupillary distance varied between subjects the amount of convergence in metre angles (M.A.) is shown on the ordinate of the graph, remembering that a metre angle refers to the convergence of *each* eye at one metre, therefore total convergence at one metre is actually 2 M.A.[11] The average I.P.D. of the

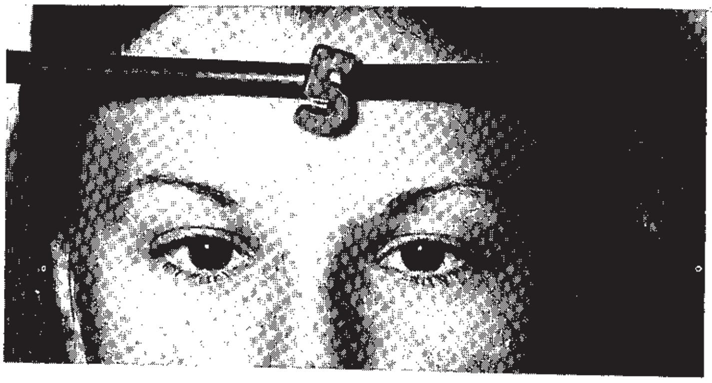
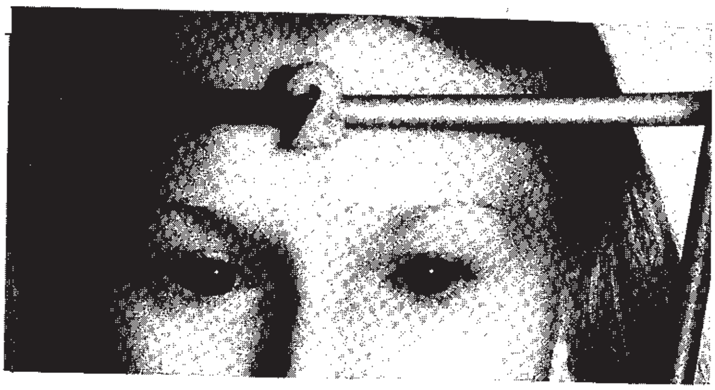


FIG. 1

FIG. 2



subjects was 6.2cms and the equivalent convergence in prism dioptres is included in brackets. Because this method proved to be a suitable way of measuring convergence (see results) the resultant measurements could then be used as a basis on which to evaluate those measurements taken in the dark.

3. The photographs were repeated at exactly the same distance in total darkness, using infra red photography, whilst the subjects were asked to reach out and touch the target and imagine that they were looking at it. (Figure 2)
   Therefore the only clues to its distance were from the proprioceptive receptors in the arm. Surprisingly, most subjects, although unsure of their ability to do this when it was first explained, found that it did not seem to be difficult to perform. The head was kept steady by a head rest.
4. The resulting photographs were enlarged to exactly the same amount as those taken in the light. Again, the interlimbal distance was measured, and by comparing it with that obtained in the light, the proximal convergence could be measured.

Results

Measurements in light were obtained whilst fusion was acting. These data were converted to metre angles and plotted against the distance from the eyes, in centimetres, of the target. The results of this plot can be seen, along with the curve of best fit, in Figure 3.

The parabolic curve of best fit, shown in Figure 3, has, as its equation

$$C^1 = \frac{3.3}{D + 0.05} - 2 \qquad (1)$$

where C^1 is the convergence in metre angles, and
D is the distance of the object from the eyes in metres.

As pointed out earlier the theoretical curve is

$$C = 2/D \qquad (2)$$

but comparison of the mean observed convergence measurements with those predicted from equation (2) yielded a correlation coefficient of 0.09 ($p < 0.005$). Thus, variations between values obtained from equations (1) and (2) for the same value of D being significantly different due to anything other than chance has probability of 1/200 for the specified range of D, i.e. less than 0.50 metres. Differences between the observed values of C and the theoretical values of C are consequently

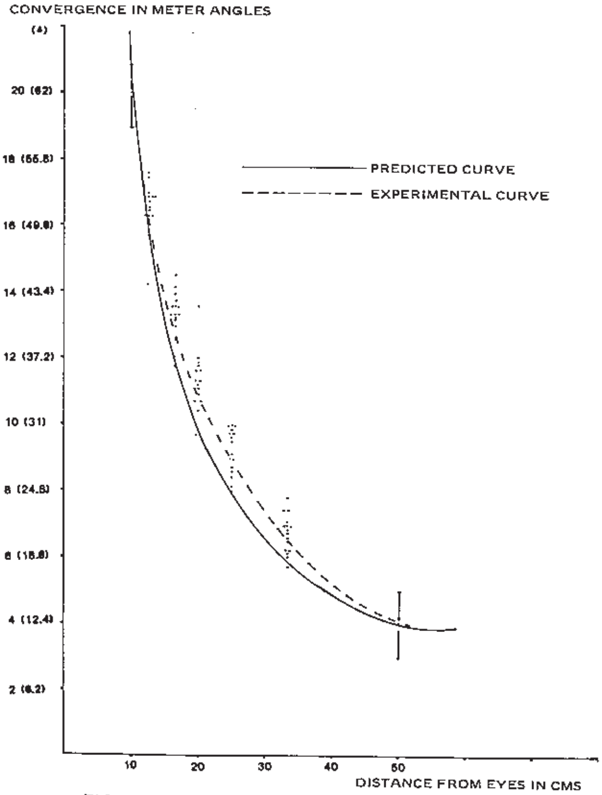


FIGURE 3 CONVERGENCE IN THE LIGHT

well within the bounds permitted by sampling error.

Data obtained from measurements of convergence in the dark are plotted in Figure 4 and 5. In Figure 4 the curve of best fit, parabolic, has been drawn along with that obtained for convergence in the light. The equation of the latter is given above, equation (1), while the equation of the former is

$$C^1 = \frac{2.58}{y + 0.05} + 1.318 \qquad (3)$$

The mean values with standard deviations for each distance are shown in Figure 6.

Some observations can be noted from the data presented in Figure 4 and 5:

1. While the curve of best fit is parabolic, there is, on the part of the subjects, a tendency in the dark to show a stronger convergence response for distances 50cm – 12 cm. For distances less than 12cm the "dark" response is more reduced. Although, overall, showing a greater response than for "light" again the values from the theoretical curve, equation (2) correlate largely ($r = 0.99$, $p < 0.005$) with the observed mean values.

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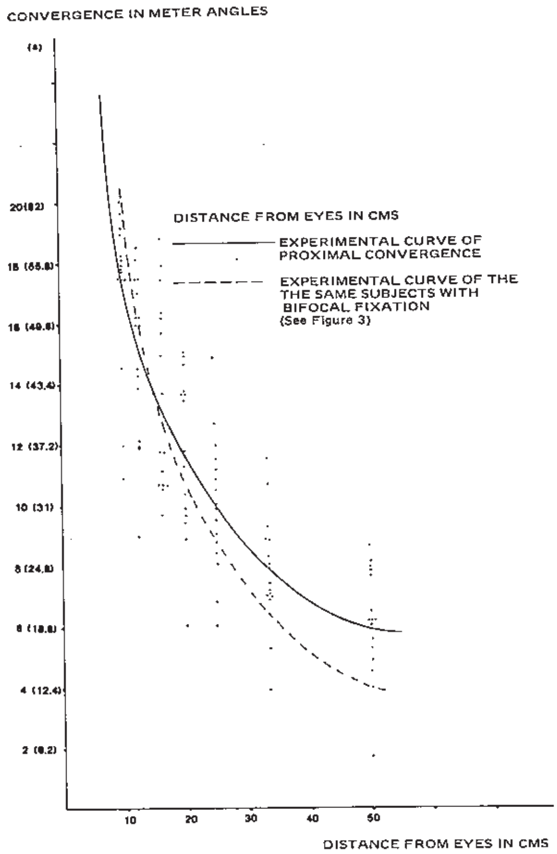

FIGURE 4 PROXIMAL CONVERGENCE

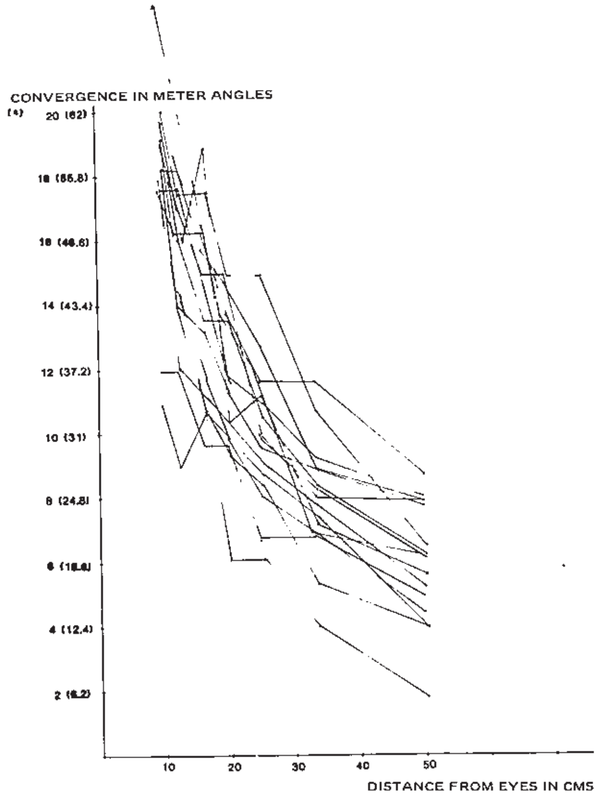

FIGURE 5 INDIVIDUAL RESPONSES TO PROXIMAL CONVERGENCE

DISTANCE	50 cms	33.3cms	25cms	20cms	16.6cms	12.5cms	10cms
Equivalent dioptres of accommodation	2	3	4	5	6	8	10
Mean (Δ)	18.5	24.5	31.1	35.7	43.8	46.6	57
Standard Deviation (Δ)	5.8	5.7	6.9	8	9.2	8.3	11.6

FIGURE 6 Mean values and standard deviations of measurements of proximal convergence

2. For individual data obtained in the dark there is a much wider scatter of values of C^1 for any given value of D. This can be seen in Figure 4 and is supported by the fact that for predicted data the error mean square is 0.3741 for the dark and 0.0632 for the light. Altogether there does exist a large variability between individuals in the "dark" responses, Figure 5 illustrates that within individuals the performance is consistent for each distance (D). Variations between individuals can be likened to individual variations in the AC/A ratio.
3. The pattern of reduced response for close distances described above is supportive of the findings of Schapero and Levy[6]. The fact that the eyes tend to take up a slight convergent angle for distance in the absence of visual clues is a well known fact (space myopia). This may also be a manifestation of proximal convergence as it is probable that the more normal position of 'relaxed' fixation in everyday life is around 5 – 6 metres, rather than infinity.

4. For thirteen of the subjects, proximal convergence measured by this technique was, at least for the further distances, in excess of the required convergence, although these subjects did not normally show an esophoria. This could be explained by at least two factors:
   i) That proximal convergence is a vigorous response to nearness which is modified in the normal environment by the more accurate visual clues to proximity such as perceived size and the relationship of objects to others. Information derived from accommodation may also modify its response.
   ii) That the judgement of distance by this technique, i.e. from proprioceptive clues from the muscles of the arm, was inaccurate.

Nevertheless, the dramatic response of convergence in the absence of accommodative clues and fusion, does indicate a greater importance of proximal convergence in the near deviation than has been described by previous techniques.

CONCLUSIONS

Proximal convergence, as measured by the technique described above, shows stronger response than previously predicted for near. This conclusion is supported by the data obtained for distances at 33.3cm (at which near measurements are taken) which yield a mean convergence of 7.9 M.A. (24.5△) with a standard deviation of 1.79 M.A. (5.7△).

As the distance of the target from the subject is increased the response is still in excess of that required at 50cm. This pattern is also repeated for the distances 25cm, 20cm and 16cm. For distances closer than 16cm the mean convergence obtained was less than that predicted.

Although some variations from what had been predicted have been obtained, the overall pattern for proximal convergence agrees with what had previously been predicted. This paper has presented a technique whereby measurements can be obtained in the total absence of visual stimuli.

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