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CONFERENCE PAPER

How to use an adaptive optical approach to correct vision globally†

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Abstract

It is estimated that about one billion people in the Developing World would benefit immediately from distance vision and near vision correction if it were available to them. Here we address this problem by correcting vision in the field with adaptive liquid filled variable focus lenses, and test whether it is possible by simple means to determine and obtain correct refraction using such lenses.

For nearly one billion people in the Developing World[1] currently without the vision correction they require, the benefits of providing a simple and inexpensive means of correcting refractive error are clear, since poor vision can hinder a child's educational development and an adult's productivity at work. Studies have demonstrated the prevalence of visual impairment amongst children. A study performed in Shunyi District, China[2], sampling a total of 6134 children revealed that by the age of 15 years 46% of children were myopic (<– 0.5 D) and that the prevalence of uncorrected vision in at least one eye was 13%. It also showed that refractive error was the cause in 89% of the 1236 eyes with reduced vision. Results from a study[3] in La Florida, Chile, indicate that more than 7% of school-age children could benefit from the provision of proper spectacles. It concluded that efforts are needed to make existing programs that provide free spectacles to school children more effective. Another study in India[4] established that, for children between the ages of 7 and 15 years, 70% of those that had visual acuity of 20/40 or worse would benefit from spectacles. The study recommended that effective strategies be developed to eliminate this easily treated cause of visual impairment.

To give a broader indication of the proportion of adults that need vision correction for ametropia an average can be found from the results published by the three surveys of Strömberg (1936), Stenström (1946), and Sorsby *et al* (1960)[5]. A total of 8187 eyes of adults under 35 years of age were tested and 67% required correction for ametropia, defined, in these studies, by the need of a correction of magnitude greater than 1 dioptre. Another study in the United States using results from the 1971–1972 National Health and Nutrition Examination Survey showed that the prevalence of myopia among persons between 12 and 54 years was over 24%. A comprehensive Ministry of Health survey[7] in the UK in 1962 of the distance prescriptions made showed that 91% were in the range – 6 D to + 4 D.

The conventional approach to delivering vision correction to very large and as yet essentially unserved populations is to attempt to use appropriately trained staff to carry out a refraction, producing an individual prescription, and then making up spectacles to that prescription. Serving a developing world population in this way will require the training and retention of a very large number of eyecare professionals (as many as 250000 if we use a ratio of one practitioner per 4000 of the population) as

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well as the training of many ancillary staff, and the setting up of a complete distribution system. It is hard to see how this approach could scale globally to serve up to a billion people over a reasonably short time scale. An alternative approach begins with an examination of the way the eye-brain adaptive optical systems function. For an emmetropic subject the feedback systems operate so as to maintain more or less sharp focus on the retina as the subject views objects at different distances. If the subject needs vision correction, it may be considered that the range of focus of the eyelens is not sufficient. One way to deal with this condition is to equip the subject with external adaptive lenses, one for each eye, which may be separately adjusted so as to get to the sharp focus condition - and the whole " system" (adaptive lens + manual controller) may be looked upon as simply a further feedback loop, additional principally to the internal accommodative feedback loop for each eye. Given the known incidence of refractive error detailed above, using an adaptive lens with a variable power between – 6 D and + 6 D, the vast majority of prescription refractions could be achieved, and in effect the subject can be thought of as correcting their own vision. If the lens can only correct spherical ametropia, its usefulness should not be greatly reduced, as demonstrated by the Ministry of Health survey which showed that of the prescription spectacle wearing population a very large proportion (84%) required a cylinder correction of less than 1 D, though of course one might expect variations in the incidence of astigmatism from population to population.

The Adspec lens

For a lens to be suitable for correcting human vision the optical quality of the lens must be at or above that of the human eye itself if it is not to introduce additional aberrations reducing image quality. For the case of monochromatic light, the wave aberrations of the eye have been characterised by *Porter et al*[9] and Guirao *et al*[10] who showed that for a 5.7 mm pupil the total rms wavefront error arising from contributions other than defocus was approximately 0.9 µm. Using this criterion as a guide, we have designed a variable power spherical lens. Two thin membranes are sealed and stretched at a circular perimeter of diameter 42 mm by a circular frame and the volume between them is filled with a liquid of refractive index 1.579. The optical power of the resulting lens is determined by the curvature of its surfaces which is controlled by varying the volume of liquid in the lens. An interferometer experiment performed on a stretched sheet of the membrane film showed that the film thickness varied by less than about ±0.4 µm per 10 mm linear displacement across its surface. This ensured that the above wave-front error would not be exceeded - in fact the wave-front error introduced by the membrane is calculated to be approximately only about 40% of that produced by the average eye. The lenses have a useful power range of –6 D to + 12 D. We then mounted two identical such adaptive lenses in a specialised spectacle frame to form adaptive spectacles, or *Adspecs*. Spectacles using liquid-filled lenses quite different from the Adspecs have been reported before[11] , but so far as we are aware, no such spectacles have been applied successfully as means of vision correction over such a wide power range until the work reported here. We developed the Adspec lens to provide an effective and inexpensive means of vision correction whereby it is possible for the wearer to adjust the refractive power of each lens to suit his or her refraction. This would make vision correction accessible to those in areas of the World where there is either a lack of professionally trained optometrists and ophthalmologists, or where the cost of traditional spectacle lenses and professional consultation is prohibitively expensive.

Methods

A preliminary field trial of the effectiveness of the Adspec lens as a means of vision correction has been performed[12]. Although the field trial included only a few subjects, it was shown that it was indeed possible to obtain good vision correction using self-adjusted Adspecs. We now present the details and results of a new and much larger field trial of the Adspec lens.

The experiments were performed in South Africa, Ghana, Malawi and Nepal and the results collated. A total of 213 participants between the ages of 18 and 65 and were selected by agencies in each country and communicated through an interpreter. Distance visual acuity was measured with either a standard Snellen chart, or an illiterate E-chart positioned at 6 m. Because of the nature of the location some of the eye tests were performed outside in daylight and so illumination was subject to variation.

The unaided vision data for each subject was recorded for each eye while occluding the fellow eye. For those subjects who could not read an entire line, the number of unread letters, N, on that line was also recorded. Then, using a conventional optometrist's trial frame refraction, an optometrist's refraction, including astigmatic error, was determined. The corresponding test lenses were constructed and their spherical and cylindrical parameters recorded for each eye. The vision test procedure was repeated with the same chart to obtain the subjects' acuities using the test lenses.

The test lenses were then removed and the subject was asked to relax their eyes by looking at a distant target. A visual target was chosen at a distance greater than 6 m and the subject was then asked to wear the Adspecs and to carry out the following adjustment protocol. Both left and right lenses were initially set to +6 D before they were worn to provide sufficient fogging to eliminate unwanted accommodation. The subjects left eyes were occluded, and they were then asked to adjust the right lens, slowly decreasing the power until the target came into sharp focus. The right eyes were then occluded, and the left eyes revealed. The subjects were subsequently asked to adjust the left lens in the same manner until the target was again in focus. Then when viewing the target binocularly, the subjects were asked to go slightly past the point of sharpest focus until the image began to blur and then turn the dial backwards slightly to achieve sharp focus again. This was based on our observation that best acuity could be achieved if a final fine adjustment was made binocularly, that is when the vergence system was functioning. Following this, the subjects were given an acuity test using the same chart as in the preceding tests. The binocular acuity obtained whilst using the Adspecs was recorded.

The Adspecs were then removed and the spherical power of each lens was determined by the method of neutralisation using a focimeter.

Results

The Snellen fractions were converted into an angle of resolution (radians) to facilitate analysis. The intermediate results where N was non-zero were assigned an angle of resolution by replacing N with the fraction of the line completed and using this to linearly interpolate between the angular resolutions of the two adjacent lines.

To compare the self-determined refractive power obtained using the Adspec lens with the optometrists refraction obtained using standard methods one must make account for the fact that the Adspec lenses used in the trial are spherical. Although a full multivariate analysis using matrix format would be desirable, it is nonetheless interesting to compare the equivalent sphere found by the optometrist with the adspec power found by the subject, the adspec lenses being essentially spherical. Optometrist refraction measurements were expressed as an equivalent spherical power S_E, where

$$S_E = S + \frac{1}{2} C \qquad (1.1)$$

where S and C are sphere and cylinder powers respectively.

If we exclude hypermetropes from the analysis and plot just the data for myopes, Figure 1, we find a linear regression line

$$y = (-0.251 \pm 0.063) + (0.949 \pm 0.047)x \qquad (1.2)$$

The slope shows a reasonable correlation but it is clear from the graph that those subjects requiring little or no correction show noticeable over-minussing, confirming that accommodation has been stimulated. This is illustrated in the residual histogram, Figure 2 where the distribution is asymmetric, skewed in the direction of negative residual values.

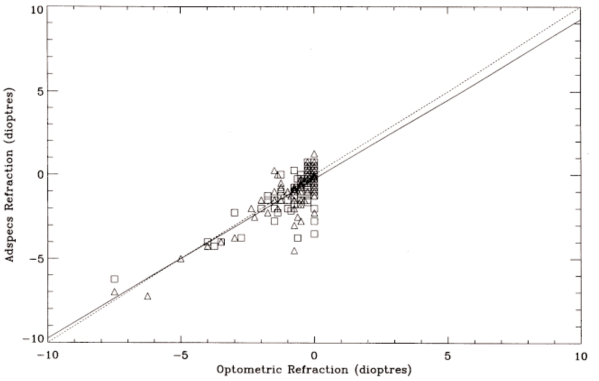

Figure 1. Myopic data only. Adspecs refraction (D) against Optometrist refraction S_E (D). Triangles = right eyes, squares = left eyes

Now isolating the hypermetropes, in Figure 3 we find the linear regression line

$$y = (-0.312 \pm 0.63) + (1.077 \pm 0.049)x. \qquad (1.3)$$

But again, the line seems to be skewed by the cluster

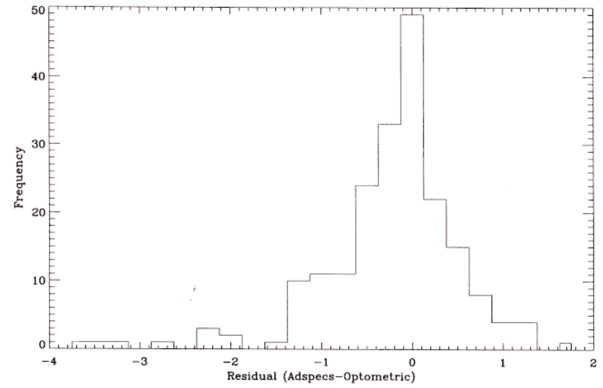

Figure 2: Myopic data only. Residual histogram showing the frequency that the residual 'Adspec-Optometrist' (D) occurred.

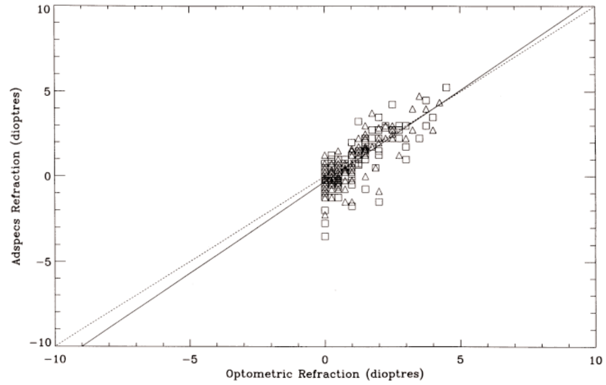

Figure 3: Hypermetropic data only. Adspecs refraction against Optometrist refraction *SE* (D). Triangles = right eyes, squares = left eyes.

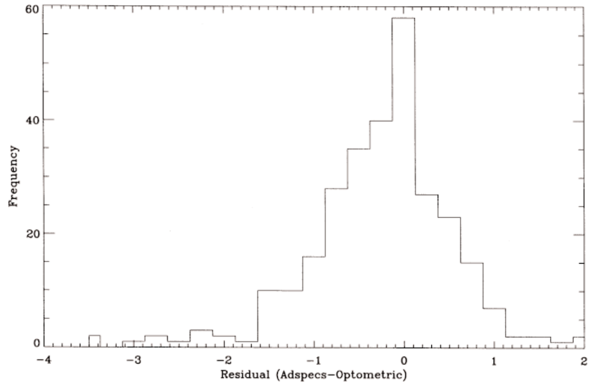

Figure 4: Hypermetropic data only. Residual Histogram, 'Adspecs- Optometrist' (D)

around selecting excessively negative Adspec powers as a result of an accommodative stimulus; the residual distribution in Figure 4 is consistent with this.

If we now remove all those subjects who require correction in the range from +1 to −1 D , we find in Figure 5 a very good agreement with the optimum line

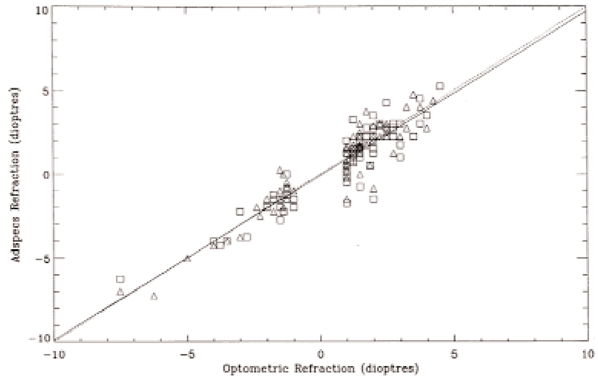

Figure 5: All data excluding subjects requiring correction in the range from +1 to −1 D . Adspecs refraction (D) against Optometrist refraction *SE* (D). Triangles = right eyes, squares = left eyes.

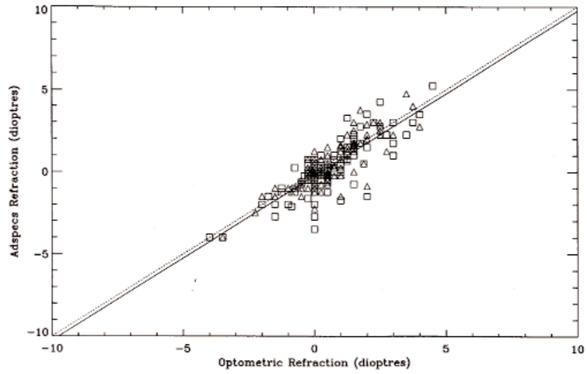

Figure 6: All data excluding astigmatic subjects requiring greater than + 0.5 D or less than −0.5 D cylinder correction. Adspecs refraction (D) against Optometrist refraction *SE* (D). Triangles = right eyes, squares = left eyes.

$$y = (-0.085 \pm 0.078) + (0.981 \pm 0.034)x \qquad (1.4)$$

This shows that, provided a protocol which minimises accommodation is used, the self-determination of refraction using the Adspec liquid filled lens is a very good method for correcting refractive error. Bearing in mind that the Adspec lens is spherical we can also now look at the data for just those subjects who suffer from little or no astigmatism

If we remove all those subjects requiring greater than + 0.5 D or less than − 0.5 D cylinder correction, we are arrive at the 'non-astigmatic' data plotted in Figure 6, with the line of best fit

$$y = (-0.257 \pm 0.051) + (1.000 \pm 0.041)x \qquad (1.5)$$

The exceptional closeness of this fit demonstrates the combined effectiveness of this method with the Adspec lens for correcting spherical ametropia and the ease and accuracy with which subjects can determine their own refractive correction.

Conclusion

The comparisons between the self obtained Adspec refractions and the optometrist refractions (S_E) demonstrate the success of this method. This conclusion is strengthened if account is made of the uncertainty inherent in current methods of automated and clinical refraction[13].

The efficacy of this method in practice and the benefit that Adspecs can provide in real terms can best be illustrated by a comparison of the monocular acuity histograms. The unaided vision test results are displayed in the histogram of Figure 7, and the acuity distribution obtained after self-correction with the Adspec lens is shown in Figure 8. Where a subject had little or no vision in one eye, the monocular acuity of their good eye has been included in the histograms. It is seen from the unaided vision distribution that the great majority, some 78%, of this sample cannot obtain 6/6 vision and therefore require some sort of vision correction. After the self-adjustment procedure with the Adspecs just 13% of the sample had acuity worse than 6/9. So, by the simple use of the Adspecs, 87% of this sample population could obtain eyesight of sufficient quality to satisfy the current DVLA* minimum vision requirement. This type of vision improvement can have a very significant and immediate impact on the lives of people from developing nations who would otherwise be excluded from education or employment. Two separate studies were performed last year, one investigating the impact that the Adspecs can have on productivity in the work place, and the other exploring their effect on adult literacy. The first study examined the effect on Indian cotton mill workers, where it was found that 44% of those workers that required vision correction improved their productivity output by more than 10% on previous levels. The second study, of adult literacy classes in Ghana, showed that amongst the adult learners who had dropped out of their class, 93% were found to need vision correction.

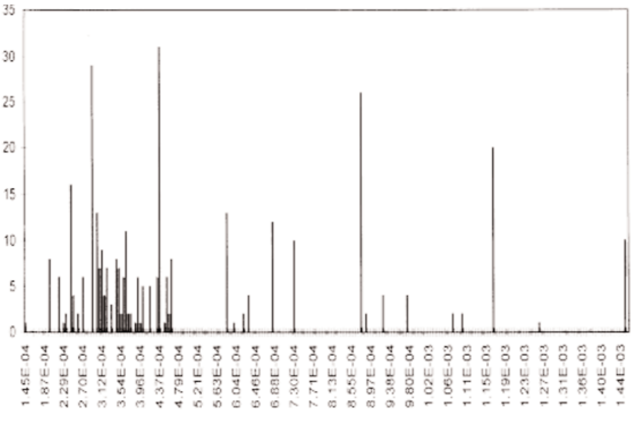

Figure 7: Histogram showing the frequency distribution (y-axis) of the recorded unaided monocular vision (x-axis). Vision is recorded as the minimum angle (radians) resolvable.

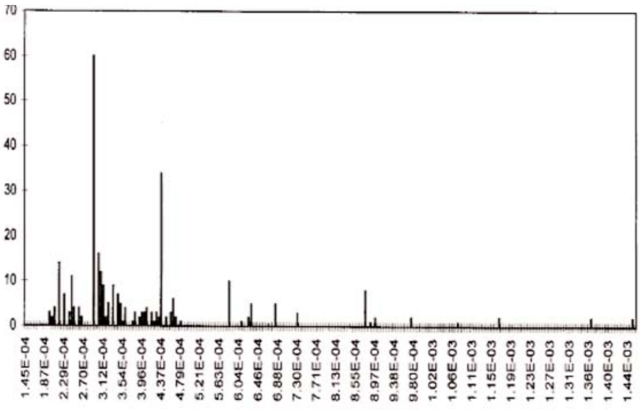

Figure 8: Histogram showing the frequency distribution (y-axis) of the recorded monocular acuity after correction with Adspecs (x-axis). Acuity is recorded as the minimum angle (radians) resolvable.

To summarise, not only do the Adspecs provide a means of affordable corrective eye wear, but also a means of accurately determining one's own refraction. Taken together, one can conclude that the Adspecs can provide a solution to the problem stated in the introduction.

Discussion

The present study includes only adults. There are two reasons for this: first it was thought that an understanding of the protocol is needed, this is difficult enough with a language and social barrier, second, a child's eye has a vastly increased range of accommodation. The problem of determining the correct refraction for children needs further investigation. But with the intuitive means with which the Adspecs can be adjusted to obtain clear vision, which is apparent from the results of this experiment, they may provide one way to solve the difficult problem of determining a child's refraction if this determination is carried out by someone with an appropriate level of training.

The continuous mode of self adjustment may facilitate more reliable refractions than currently available using standard subjective clinical refraction techniques where the 95% limits of agreement are between –0.90

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* In the UK the Driver and Vehicle Licencing Agency require that new drivers have acuity that is at least 6/9 on the Snellen scale in tthe better eye and 6/12 on the Snellen scale in the other eye.

D and + 0.65 D[13]. Compound this error with test lenses graduated in 0.25 D steps and the advantages of a continuous method are reinforced.

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