Vision Correction in the Developing World

Perhaps the largest application of Adaptive Optics?

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Abstract

The global unmet need for corrective eyewear is very large - at least 1 billion people. To achieve correction to 20/20 vision, that need is arguably more like 3 billion people. The current global efforts are completely inadequate if a significant change in these numbers is to be achieved.

The Centre for Vision in the Developing World is a new research group dedicated to pursuing research relevant to tackling this unmet need, in particular for the very large number of people in the world who cannot access eye care professionals or obtain prescription eyeglasses.

In order to effectively accomplish our goals a diverse range of topics must be tackled. Therefore, our interests include the following pursuits:

•Establishing a better measurement of the global unmet need for vision correction using visual performance as a criterion.

•Investigating how to measure refractive error with minimal recourse to highly trained professionals. In particular, investigating an approach whereby the user adjusts their own correction to achieve best focus - a process we term self-refraction.

•Determining the validity of a putative solution based on simple, self-adjustable eyeglasses. This includes determining the extent to which such a solution may be applied, for example to children and teenagers.

•Pursuing matters of vision research that arise incidentally from our work. For example, investigating feedback dynamics of the accommodative system.

We are constantly developing our ideas and we invite thoughts and comments on our efforts. We would also welcome discussions with anyone interested in collaborating with us in our efforts.

The Global need for vision correction

•A WHO working group which studied the need for corrective eyewear concluded in 1987 that "the sight of one-fifth of the population could be improved by the use of spectacles, including the sight of about 10% of schoolchildren"[1].

•Unfortunately, it is unclear what the visual acuity/refractive error criteria used were, or whether the estimate took presbyopia into account.

•A recent study evaluating the prevalence of refractive error in the United States[2], however, suggests that 'clinically important refractive error* affects half the US population 20 years or older'. These data were based on the 1999-2004 National Health and Nutrition Eye Examination Survey (NHANES).

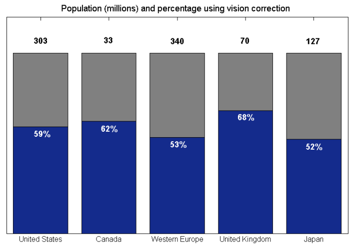
•Consumer market research data based[3] on unit sales of eyeglasses per individual the US, Japan, Canada, Western Europe and the United Kingdom bear the results of the NHANES report out (see accompanying figure).

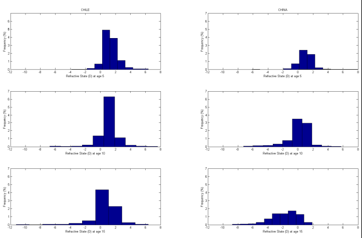
•The incidence of childhood refractive error has been measured in a variety of settings by the Refractive Error Study in Children[4-12] (RESC) task groups. These studies have shown conclusively that Refractive state varies as a function of age, socioeconomic status, and ethnicity. The refractive data for over 38,000 children between the ages of 5 and 16 years indicates that at least 10% of all children require vision correction for myopia.

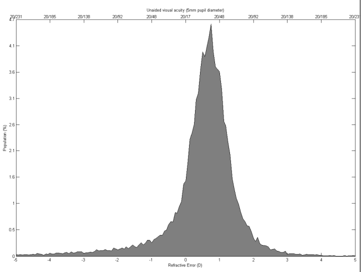
•One of the difficulties in estimating the global burden of refractive error is the issue of hyperopia in pre-presbyopes, and children in particular. Given the accommodative amplitude of the average child, at what point do we consider hyperopia to be a 'significant' refractive error? While it remains true that eye care professionals are able to study the interaction of hyperopia, accommodation and vergence on a child-by-child basis, there is little agreement on how hyperopia should be treated in global context.

		Population in age group (millions)	People requiring vision correction (millions)
Children (age < 16 years)	Myopic	1,830	165 (9%)
	Hyperopic		≈ 650 (30%)
Non-presbyopic adults (16 ≥ age > 45 years)		3,154	Unknown
Presbyopes (age ≥ 45 years)		1,720	> 1,380 (> 80%)
		Total	**> 2,000**

*Clinically important refractive error was defined as hyperopia of 3D or more, myopia of 1D or more and astigmatism of 1D or more in either eye.







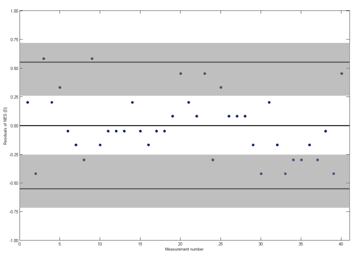
Conventional approaches to correcting refractive error

•The traditional method of delivering vision correction is firmly rooted in the healthcare sector and involves having an eye care professional perform an eye examination.

•This examination is designed to evaluate two important aspects of vision: the general health of the eye; and whether eyeglasses are required to improve vision. Notwithstanding the tremendous importance of the prior, the vast majority of those with poor vision will require little more than a pair of eyeglasses to improve their sight: a treatment that is at once safe, affordable, and easy to apply.

•Unfortunately, access to eyeglasses in the world's developing regions is severely limited. The reason for this is simple: the eye is ubiquitous; the eye care professional, not. South Africa has approximately 2400 eye care practitioners servicing a population of roughly 47 million people[13], a ratio of approximately 1:20,000; in Ghana the ratio of trained eye care professionals to members of the public is 1:200,000[14,15]; Ethiopia, approximately 1:1,000,000.

•This begs the question, Is there some way to address the need for vision correction in the absence of adequate access to eye care professionals?



Repeatability and Reproducibility of current methods of refraction

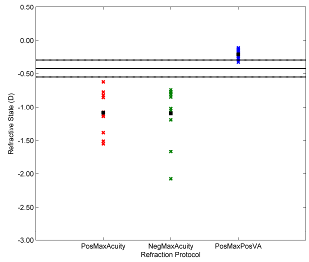
The figure above shows the 95% limits of agreement for a series of refractions performed on a single eye by 40 optometrists[16]. The residual of each measurement over the mean spherical refraction (-0.8281 D) is plotted against the vertical axis. The solid black line located along 0.00D represents the mean residual and the lines above and below it represent the upper and lower limits of agreement at the 95% level of confidence (±0.55 D). The reproducibility limit for this method of refraction is 0.78D. The findings of this research suggest that refractions performed by multiple optometrists on a single eye will differ over 0.78 D on average not more than once in 20 refractions. The grey shaded areas span the 95% limits of agreement for a number of commercially available autorefractors[17-20]. The reproducibility limits for these instruments range from 0.35D to 1.00D.

Self Refraction

A potential solution to the shortfall in eye care professionals in developing countries is to allow people to correct their own vision using eyeglasses with adaptive lenses. Adjustable eyeglasses offer the user the ability to change the power of each lens independently to improve vision in each eye: a process known as self-refraction. Adjustable eyeglasses thus have the potential to provide a means of both measuring and correcting refractive error in regions underserved by eye care professionals.

The accompanying figure demonstrates the outcomes of self refraction for three different refraction protocols (see below). Ten measurement were recorded for each refraction protocol.

1. PosMaxAcuity: The subject begins the self refraction procedure with the adjustable lens set to 3.00D and is instructed to adjust the lens power to achieve highest resolution
2. NegMaxAcuity: The subject begins the self refraction procedure with the adjustable lens set to –3.00D and is instructed to adjust the lens power to achieve highest resolution.
3. PosMaxPosVA: The subject repeats the PosMaxVA procedure. Once completed the subject is instructed to slowly increase the lens power until they perceive the slightest defocus.

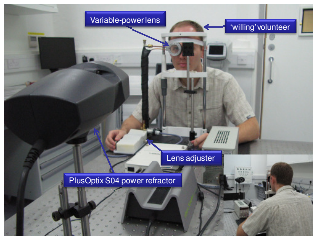


The solid black line indicates the subject's mean refraction as measured using a Nidek TonoRef 2 autorefractor. The broken black lines indicate repeatability limits of these data (n = 30) at the 95% level of confidence.

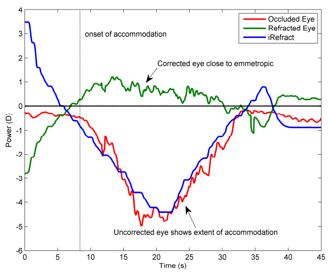
A laboratory tool for studying self-refraction – iRefract

A potential problem with the use of self-refraction is that of stimulating accommodation. It is therefore important that we develop a good understanding of the accommodative system and the interaction of this system with the self-refraction process.

To this end we have developed a simple laboratory experiment, iRefract, for collecting data during the self-refraction process. Essentially the apparatus consists of a homemade variable powered liquid lens system used in conjunction with a commercial instrument, the PlusOptix S04 Power Refractor. Only a single lens is used, in front of the other eye is situated a filter that blocks visible light but transmits in the near infrared (as used by the power refractor). The power refractor provides real-time, binocular data for the uncorrected, occluded eye as well as the eye plus variable power lens combination. In addition to measuring refractive error data is also provided on pupil size and gaze direction both of which can also provide useful information on the accommodative system. By synchronizing this data with what we record from the lens we can determine what a subject is doing and how their eyes are behaving.



Our first generation instrument is suitable for recording the self-refraction process. The graph on the right shows the time history of a typical measurement. Starting from a high positive power on the lens, corresponding to a negative refractive error, at first no accommodation is stimulated so the uncorrected eye remains constant whereas the corrected eye reflects the change in the lens power. As the power of the liquid lens is reduced accommodation is stimulated, leading to a reduction in the variation of the corrected eye and a clear change in power of the uncorrected eye. Incidentally one also notices an increase in the variability of the system as the eye 'dithers' to find the correct power. The system is then brought back to best focus and accommodation is once again largely eliminated.



We also envisage developing a substantially upgraded instrument. This will feature a more accurate measurement of refractive error, using a Shack-Hartmann wavefront sensor, and will enable rapid remote control of the lens via a servo motor system. We will also explore the correction of astigmatism. Such a device will enable further experiments, such as studies of the temporal dynamics of the accommodative system which we intend to relate to various feedback models. We can also examine effects such as accommodative spasms. There are also interesting experiments that relate to eye examinations in general – for example, we will compare step changes in refractive power with continuous changes.

Our overriding practical goal is to develop the method of self-refraction into a more robust and effective tool. However, more general vision research issues make for an interesting 'side-effect'.

Self-adjustable eyeglasses

As mentioned above, a potential solution to the unmet need for the correction of refractive error is to deploy eyeglasses featuring variable power lenses. Such eyeglasses can then be adjusted by the wearer who follows a defined protocol in order to arrive at a good approximation of their required correction. The use of wearer adjusted eyeglasses is applicable to both distance and near vision problems and so can help both myopes, hyperopes and presbyopes.

This approach chiefly solves two problems: First, it reduces the need for measurement by a trained refractionist, which is crucial for regions with few eye care professionals. Secondly, it offers a much simpler and far cheaper deployment compared to a more conventional approach based on lens grinding or stock optics.

To date approximately 30,000 units of a first generation product have been deployed in the field[21], most via an adult literacy programme run by the Non-Formal Education Division (NFED) of the Ghanaian Ministry of Education and via the humanitarian arm of the US Government's AFRICOM division. This product has a power range of -6 to +6 dioptres and uses liquid filled lenses which are set to the required power by the use of external adjusters which are then removed. A commercial partner is now working on a next generation product which features a much improved appearance, and a significantly reduced production cost.

Another possible use of variable power lenses is to provide ongoing adjustment over a smaller range of power. For example, with a range of +1 to+ 4 dioptres one can provide a "universal" reading eyeglass that could then be shared by a number of users, such as members of a family. A device that fulfils this requirement is nearing completion.

Child Vision Study

The problem of stimulating accommodation as part of the self-refraction process is much worse with younger individuals, especially children. We have therefore instigated a study into the efficacy of self-refraction with younger people, funded by the World Bank. The first phase of this study will compare self-refraction based measurements of refractive error with results obtained by non-cycloplegic and cycloplegic auto-refraction, and cycloplegic subjective refraction. Working with our partners in Boston and China data collection for this study will start in January 2009, and results are expected in the second-half of 2009. In the first instance we will be working with teenagers aged 13 to 16 years old, work with children will then follow on.

There remain considerable challenges with our proposed approach to vision correction. For example, although we can correct many individuals our approach is not truly universal. Severe myopes or high astigmats will require other solutions, as will individuals with more exotic refractive problems (such as keratoconus) and those suffering from non-refraction related vision problems. It is hoped that we might be able to screen for such individuals as part of a supervised self-refraction protocol, but this requires further work to determine.

There also exist many challenges related to deployment, as well as the obvious problem of cost there are also a number of psychological barriers. Nevertheless despite these challenges we have been very much encouraged by the radical improvements to a person's vision that can be achieved with our simple solution and we remain optimistic that with adequate resources we can help millions of people to see clearly.

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