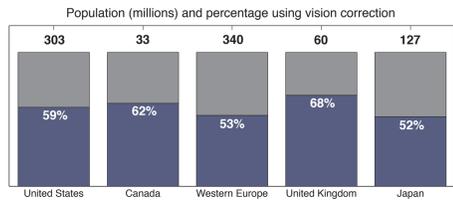




## Abstract

The simplest way to get an estimate of the global need for corrective eyewear is to look at what fraction of a developed world population wears or has some form of vision correction (as shown in the diagram), and then extrapolate<sup>1,2</sup>.



Estimating the global need can also be accomplished by using a distribution of refractive error, and setting an acuity criterion, which then enables us to estimate the fraction of a population who will be able to see to that acuity by using a refractive error-visual acuity relation (REVAR). Using this estimate we are able to estimate the global need for ametropic corrective eyewear, and separately the need for presbyopic correction.

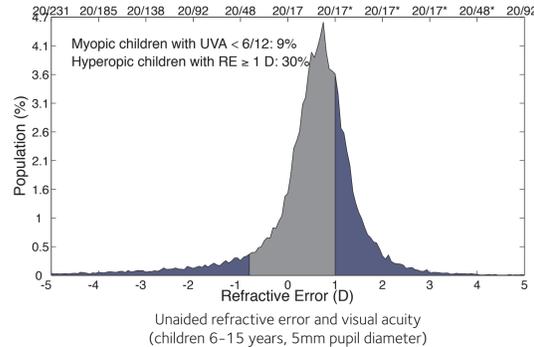
## Estimating the need for vision correction

Using a REVAR we can set a visual acuity criterion and use refractive error distribution data to determine how many people fall below this.

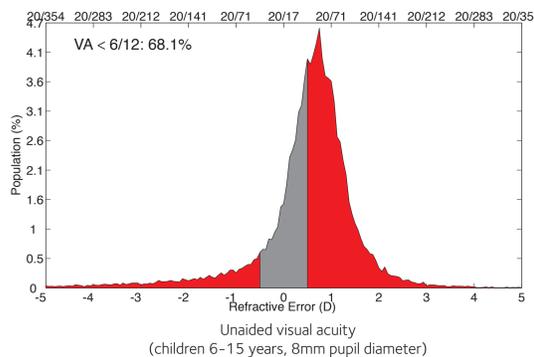
Distributions of refractive error vary from one population to another and as yet there are no complete global statistics for adults, only scattered studies. For children, however, there has been a large population based study of 38,000 subjects in several countries<sup>7-15</sup>.

Using a typical visual acuity criterion of 6/12 (20/40) (based on US legal driving requirement<sup>4-6</sup>) and assuming a pupil diameter (5mm) we can make an initial determination of:

- the percentage of the population who are myopic such as to not satisfy the acuity criterion (9%)
- the percentage of the population who are hyperopic such as to not satisfy the acuity criterion or, in the case of children\*, an arbitrary refractive error criterion (1D hyperopia) criterion (30%)



This number will vary depending on the acuity criterion and the assumed pupil diameter, as demonstrated in the second chart, with a wider pupil.



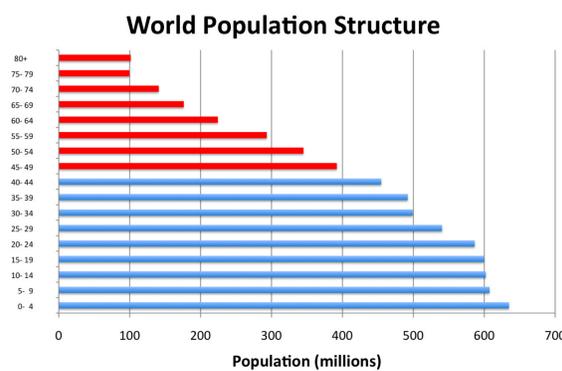
An accurate estimate for the adult non-presbyopic population would require refractive error distribution data for adult populations, and an improved REVAR.

\*where the amplitude of accommodation is sufficient to compensate for some degree of hyperopia

## Presbyopes

The vast majority of presbyopes worldwide need close vision corrective eyewear.

If we assume everyone over the age of 45 is presbyopic (as indicated in red on the chart), this implies that over one quarter of the world's population, approximately 1.8 billion people, require close vision correction.



Myopes also suffering from presbyopia may not require close vision correction, but will still require distance correction.

## Conclusions

Given the 20/40 visual acuity criterion and the simple REVAR, and excluding non-presbyopic adults who may require distance correction, the table indicates that at least 33% of the world's population (presbyopes and children) could benefit from vision correction.

The distribution of refractive error in the non-presbyopic adult population (approximately 3.2 billion people) is not fully known, but a low estimate of the need for vision correction in this age group would be 30% (950 million).

Our estimate for the global need for vision correction thus is at least 45%. This figure is in fair agreement, but still lower than, the fraction of people known to be wearing corrective eyewear in the developed world.

		Population in age group (millions)	People requiring correction (millions)
Children (age < 16 years)	Myopic	1,844	166 (9%)
	Hyperopic		~553 (30%)
Non-presbyopic adults (16 - 45 years)		3,172	Unknown (estimate at 30% ~ 950)
Presbyopes (age > 45 years)		1,773	> 1420 (>80%)
		Total	> 3089 (approx)

Source: US Census Bureau International Database (2009 figures)

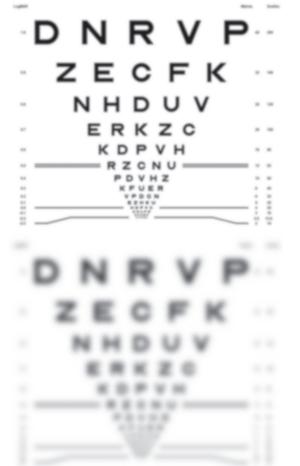
## Problems with measuring visual acuity

Direct measurements of visual acuity are a direct measure of how well a patient sees, but suffer from a number of problems:

- Lighting and environmental conditions change the pupil diameter, changing image blur for a constant refractive error
- Measurements depend on patient co-operation and understanding
- Failure conditions for an optotype line are arbitrary and there is an associated (but not well understood) measurement noise

Measurement of refractive error is more robust for comparisons and epidemiology as it is much less sensitive to the environmental and measurement conditions, and can be measured more accurately and reliably.

Current WHO estimates on requirements for refractive correction are based on visual acuity distribution data and a visual acuity criterion of 6/18 (20/60).

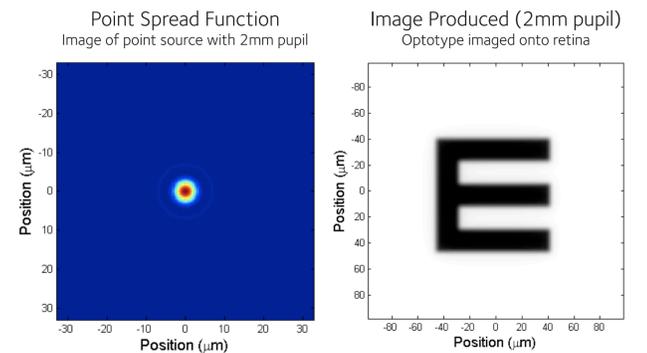


Acuity charts as viewed with a refractive error of -2.0D with 3mm pupil (top) and 8mm pupil (bottom).

## Visual acuity from refractive error

### Emmetropic Eye

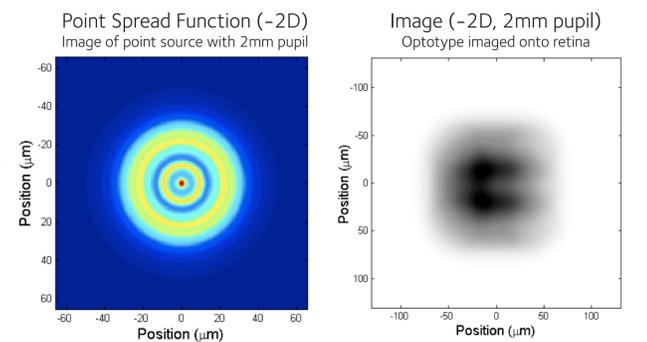
If one observes a point source, the image (light of wavelength  $\lambda$ ) is blurred by diffraction from the pupil diameter ( $d$ ). (Rayleigh criterion:  $1.22\lambda/d$ )



For an emmetropic eye with a pupil diameter of 4mm, and yellow light ( $\lambda=590\text{nm}$ ), the minimum spot size on the retina corresponds to an angular resolution of a little over half a minute of arc. Detail finer than this cannot be resolved.

### Ametropic Eye

If the eye is ametropic the degree of blurring – and hence the subject's best achievable acuity – is determined by defocus and diffraction effects<sup>3</sup>. Theory leads to the image and point spread functions on the retina as shown on the right.

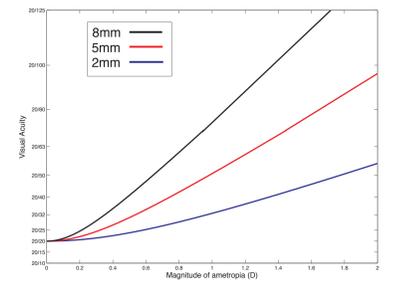


The diagrams show the point spread function and defocus for a -2.0D myopic eye.

It should be noted that the REVAR used here and in our numerical predictions is a simple model based on empirical observations. A summary of different results and models is given by Smith (1991)<sup>3</sup>. Using this model, Smith predicts a REVAR of

$$A = kD_{mm} E$$

where  $A$  = visual acuity,  $D_{mm}$  = pupil diameter in mm and  $E$  = refractive error in dioptres. Smith predicts  $k$  to be 1.41, however clinical studies have given  $k$  with a range of 0.55 to 1.33 with a mean of 0.83 (used in our estimate), indicating that this relationship is still not well understood.



We have found that REVARs derived from simple optical models cannot produce results consistent with observed data. We are currently investigating whether other phenomena, such as the Stiles-Crawford effects, and both static and dynamic visual processing by both the eye and brain can explain such discrepancies and so point to a potentially interesting area for further research.

## Comparisons

The figure presented here (~3 billion) is considerably higher than previous estimates, most notably that of the World Health Organization, which estimates that there are around 153 million people<sup>16</sup> who currently lack but require distance vision correction and 1 billion suffering from 'functional presbyopia', claiming that only 410 million of these lack and would benefit from near vision correction<sup>17</sup>.



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