Simple magnifiers available for general purchase are usually single bi-convex lenses of +4 to +6 D held between the eye and a page of print to give an enlarged image and better vision for fine detail. Magnifiers of higher powers than this have been used as low vision aids for many years and have a special place in the clinical procedures of the low vision optometrist as convenient, portable and practical devices. The word ‘simple’ denotes the positive lens format of a magnifier rather than a telescopic or compound microscopic design. However, modern magnifiers of good quality are anything but simple. Aspheric lens surfaces or aplanatic designs reduce spherical aberration, careful choices of front and back lens curvatures provide flat fields and clear peripheral imagery, and quality resin materials and scratch-protective coatings make them lightweight and robust for regular use.

Chinese scholars used magnifiers centuries before use in Western countries was known. In 1269, Friar Roger Bacon was a noted user reported in early English literature but the fictitious British detective Sherlock Holmes is most associated with the ‘spyglass’. No doubt, Holmes benefited from the magnification but his adventures were written before the time that presbyopic spectacles were readily available. Probably, his ophthalmologist author was more familiar with the use of this lens as a correction for presbyopia than as a simple magnifier, carefully adjusting the distance of the lens from the clue to give a sharp retinal image.

In this paper, I review the optics of the simple magnifier and explain why actual image enlargement might vary from a manufacturer’s specifications. Understanding the optics of these devices and how they are used enables us to prescribe magnifiers with confidence that they will meet our patients’ needs.

What are the optics of simple magnifiers?
A simple magnifying lens is a positive power lens of dioptric power $F_m$ and effective aperture width $A$ mm placed between a page of print and a reader’s eye. The page is always closer to the magnifier than its focal length $f_m$ if the image is to be upright.

The image is always further away from the magnifier than the page. For clear vision, the image should be $f_m$ metres from the reader’s eye, a distance appropriate for the accommodation of the eye $F$, or the power of any reading spectacles worn.

In Figure 1, a reader holds a magnifier $F_m$ a distance $z$ metres from the eye and the page ($y$) a distance $l$ metres from the magnifier. The image ($y’$) is enlarged but
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virtual, a further distance $l'$ from the magnifier. The eye-to-image distance is the sum of $z$ and $l'$ and this should be a distance similar to $f_a$, the focal length of the spectacle lens near addition $F_a$ (or for a non-presbyopic reader, accommodation $F_a$), if the image is to be sharply focused on the retina. The ratio of image and page distances $l'/l$ or page and image vergences $L/L'$ is the transverse magnification or enlargement ratio ER. Based on similar triangles, this ratio is the same as $y'/y$, the ratio of image to object height. Image and object vergences are related to $F_m$ by the simple lens formula:

$$L' - L = F_m. \quad [1]$$

If a patient uses reading spectacles alone, the page must be placed at $y_1$ for a sharply focussed image.

Field of view, expressed as the linear width of the page $W$ (mm) visible through $F_m$, is related to the aperture width $A$ of the magnifier by the relationship:

$$W = A/F_e z \quad [2]$$

where $F_e$ is the equivalent viewing power (EVP) of $F_m$ and $F_a$ in combination, separated by the magnifier-to-eye distance $z$. Dimensions $A$ and $W$ must be expressed in the same units.

We define $F_e$ by the relationship:

$$F_e = F_m + F_a - (zF_mF_a) \quad [3]$$

This is the well-known formula for two lenses separated by an air gap. We measure $z$ in millimetres but express it in metres in Equations 2 and 3 for correctness of dimension.

How does the reader manipulate these distances to obtain a clear view of the page through the magnifier?

The reader can hold a magnifier in a range of positions (Figure 2). At one extreme (Figure 2a), she places it against the page held $f_a$ metres from her eye. Here, $z = f_a$ and $F_e = F_a$, and there is no image enlargement from the magnifier.

At the other extreme (Figure 2c), she holds the magnifier against her spectacle reading lens $F_a$ so that they almost touch. At this second extreme, $z < f_m$ and $F_e > F_m$. This means that all of the dioptric power of the magnifier is available for image enlargement. Positions between these two extremes are more common (Figure 2b). These relationships between ER, $W$ and $z$ are shown in Figure 3. For the first extreme, there is no benefit of image enlargement and for the second, the magnifier is so close to the face it can be uncomfortably impracticable.

However, let us assume that she brings the magnifier progressively closer to her eye from its original position on the page, by decreasing the distance $z$. To maintain clear vision, she must also bring the page progressively closer to her face, so that as $z$ decreases, $l$ and $l'$ increase to maintain the sum:

$$z - l' = f_a \quad [4]$$

that is, the gradually enlarging image is always in the appropriate plane for clear vision using the reader’s near spectacle lens addition $F_a$. These variations in $z$ and $l$ must also maintain the relationship $L' - L = F_m$ if the enlarged image is to remain sharply focused on the retina (Figure 2).

When we calculate this change in EVP ($F_e$), we find that there is a regular increase with every centimetre that $F_m$ is held closer to the eye, from a value $F_a$ when the magnifier is on the page ($z = f_a$) to a value of $(F_m + F_a)$, when the magnifier is against the spectacle lens ($z = 0$). In practical terms, the closer the magnifier is held to the eye, the greater the EVP and the larger the image.

When the reader brings the magnifier close to her eye, the field of view $W$ changes in a less intuitive way. When $z = f_m$, $W = A$ and there is no image enlargement. Field reduces slightly as the magnifier approaches the eye (to a value less than $A$ when $z > f_m$), then increases again to be equivalent to $A$, when $z = f_m$. As the magnifier is moved closer to the eye than $f_m$ (that is, $z < f_m$), field of view increases further, (that is, $W > A$), so that even small aperture lenses such as spectacle bifocal
A practical example

Figure 3 shows the ER of Eschenbach’s Aspheric II +12 D hand magnifier Catalogue No 2655660. This magnifier is for monocular use and is rated to have 3x magnification according to the formula $M = F_m/4$. Lens aperture A is 60 mm and the recommended magnifier-to-eye distance $z$ of 250 mm requires a magnifier-to-page distance of about 49 mm, Eschenbach’s design distance for the asphericity of lens surfaces.

In Figure 3, I plot ER that varies from 1x to 5.8x, as this magnifier is held progressively closer to the reader’s eye. At its design distance of 250 mm from the eye, the magnifier offers ER of about 2.8x ($y'/y$), compared with the view of the page at 400 mm using only the near spectacle lens addition $F_a$.

In practice, we might expect that vision impaired patients are not able to determine these distances precisely because their tolerance to a defocused image may be increased. If we accept that a patient with visual acuity of, say, 6/60 (0.1 or 20/200 or logMAR 1.0) is tolerant to ±1.0 D of defocus (an image position from 670 to 290 mm from the eye), there will be a variation in ER if magnifier-to-page distance is imprecise. This is the portion of the graph between the upper and lower ER curves in Figure 3.

What optical power of magnifier should we prescribe?

People with low vision often believe that a stronger magnifier must be better but this is not always so. Practitioners should prescribe the magnifier that offers adequate vision for the reading task required by a patient but maintains the field of view as wide as necessary. We determine this using a logMAR chart that uses a logarithmic progression of reading print size. Steps of reading improvement (decreasing print size) require the same number of steps of increase of dioptric power. In reading spectacles, for example, an improvement of near visual acuity from N12 print to N6 might require an increase in spectacle lens near addition from, say, +2 to +4 D, or perhaps +5 D.
Simple magnifiers  

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Figure 3. The relationship between enlargement ratio and field of view for different magnifier-to-eye distances. The three upper graphs show ER to decrease as z is increased, until ER is 1 when the magnifier is placed on the page and no image enlargement occurs. ER is greater if the image is out-of-focus (further away than 400 mm) by +1.0 D (top ER graph) and less if the image is out-of-focus (closer) by -1.0 D (lowest ER graph). Readers with low vision may be tolerant to some defocus because their visual acuity is reduced.

The lowest curve is the relationship between field of view W (plotted as linear field visible on the right hand ordinate) and magnifier-to-eye distance when the retinal image is in focus. When the magnifier is close to the eye the field is wide, but it reduces rapidly as z increases to be equal to the aperture size (W = A), when z = fₐ. This is the intersection point of the two dotted straight lines. These graphs show clearly that best image performance (ER and W) occur when the magnifier is held within its focal length from the eye (that is, z < fₐ). The dotted arrow signifies the design distance z chosen by Eschenbach for asphericity control. Image enlargement and field of view are smaller when the magnifier is used at this distance from the eye.

Figure 4. The relationship between enlargement ratio and field of view for different magnifier-to-page distances. The three upper graphs show ER to decrease as z is increased, until ER is 1 when the magnifier is placed on the page and no image enlargement occurs. ER is greater if the image is out-of-focus (further away than 400 mm) by +1.0 D (top ER graph) and less if the image is out-of-focus (closer) by -1.0 D (lowest ER graph). Readers with low vision may be tolerant to some defocus because their visual acuity is reduced.

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to +10 D (but a factor of 2x in each case).

Actual lens powers depend on the patient’s visual acuity impairment and thus the demand for a level of vision adequate to see the required print size. For a logMAR visual acuity chart, the general rule is that ‘at any level of the chart and at any distance from the eye, a three line increase in visual acuity represents a two times increase in visual resolution’. This means that the patient has the ability to read print of half the original size.

A two times increase in spectacle lens near addition power will guarantee a three-line improvement in near visual acuity, achieved at half the original viewing distance from the eye. However, a two times increase in dioptric power of hand-held or stand magnifiers may not yield a three-line improvement of visual resolution because magnifier-to-eye distances can vary widely.

In practical terms, I suggest we commence with hand or stand magnifiers of the following powers: +6.0 D, +10 D, +16 D, +24 D and +40 D. Each of these increases of dioptric power guarantees a two-line increase in near visual acuity over the previous power, provided each magnifier is no further away from the eye than its focal length (that is, z ≤ fₐ).

**How is magnifier-to-page distance l determined by the reader?**

When using a hand magnifier, first the lens is held a comfortable distance z from the eye. Then the page is brought closer to the magnifier until the image is seen as sharpenly as possible, that is, when l’ is of a dimension that (z – l’) = fₐ. As z is altered (the magnifier held closer or further away from the eye), magnifier-to-page distance l must be adjusted also, so that the image plane is always fₛ from the eye. Remember that l and l’ are negative values, measured in Cartesian space to the left of the lens (Figure 1).

The equivalent viewing distance (EVD) is found by determining the plane in which the original object y subtends the same angle as the new image y’. Thus, EVD = fₛ/ER, or (z – l’)/ER, using similar triangles in Figure 1. If ER = 2, then the EVD is half the eye-to-image distance, that is, (z - l’)/2. In Figure 1, this plane is between the magnifying lens and the eye at y’. The EVP is the reciprocal of the EVD and is the required near spectacle lens addition to see the page clearly in this plane.

When using a stand magnifier, the magnifier-to-page distance l is fixed. It is controlled by the height of the stand, the plastic or metal legs on which the lens is supported. In turn, this controls the position of the image l’ from the lens. For stand magnifiers, the eye-to-image distance (z - l’) is adjusted by changing the separation z of the magnifier from the eye until vision is clear, that is, when (z – l’) = fₛ. The manufacturer has greater control of image quality with stand magnifiers because lens surface design (curvature and asphericity) is adjusted to minimise spherical aberration for a given magnifier-to-page distance.

Bullimore and Bailey described methods of determining empirically the object and image distances for stand magnifiers. Object distances are short and difficult to measure, whereas image distances are longer and less subject to measurement error. These data are given by Eschenbach.
Optik in its catalogue and are set so that best vision with its magnifiers is obtained for an image plane \((z - l') = f_i\) of 400 mm from the eye. Also quoted is relative size magnification \((F_m/4,\text{ requiring } f_i = 250\text{ mm})\), although this is irrelevant in practical terms if a +2.5 D spectacle lens near addition is used. Distances \(l\) and \(l'\) are calculated from the principal planes but measured from the magnifier surfaces. Errors in measuring small values of \(l\) can be proportionally large for magnifiers of high dioptric power.

**How should we specify magnification?**

Clearly, how a magnifier is used is not within the control of the manufacturer, who labels it according to a formula based on the dioptric power of the lens. The ‘manufacturers’ specification’ \(F_m/4 + 1\) presumes the magnifier is close to the eye, spectacles are worn that offer a +4.0 D near spectacle lens addition and the reference (eye-to-image) distance \((z - l')\) is exactly 250 mm. Rarely are these constraints met. ER compares the image size with the original object size for any viewing distance, not the magnifier is close to the eye, and discomfort. It seems unnecessary to say that glare-free lighting also enhances visibility, best achieved with a convenient reading lamp that can be positioned easily, close to the page.

1. To meet image enlargement and field requirements, we should encourage patients to hold their magnifiers as close to the eye as is comfortable, usually well inside the manufacturer’s design distance. We encourage this at the cost of increasing peripheral field aberrations but where there is a tolerance to defocus, this may be an acceptable compromise. We do this at the cost of comfort and it is well-established that reading speed and fluency may be improved when magnifiers are held comfortably for extended periods. However, larger fields of view are obtained with shorter magnifier-to-eye distances. Sacrifices in rated magnification may be worth the ability to use magnifiers comfortably for extended periods. However, larger fields of view are obtained with shorter magnifier-to-eye distances. Reading speed and fluency may be improved when magnifiers are held closer to the eye. Reading requires a field of view wide enough to scan the page and sample several words at a time, whereas sewing or embroidery can be completed successfully with smaller fields of view.

2. Advice about holding magnifiers comfortably, propping up books or newspapers and resting the upper body on arms or elbows to maintain close page-to-eye distances can be the difference between success and failure (Figure 2). Eschenbach design has paid particular attention to the postural issues of magnifier use. Designers are aware that close viewing distances may lead to poor posture such as stooping, breathing difficulties and an increase in fatigue. Sacrifices in rated magnification may be worth the ability to use magnifiers comfortably for extended periods. However, larger fields of view are obtained with shorter magnifier-to-eye distances. Reading speed and fluency may be improved when magnifiers are held closer to the eye. Reading requires a field of view wide enough to scan the page and sample several words at a time, whereas sewing or embroidery can be completed successfully with smaller fields of view.

3. Another important tip makes full use of any magnifier design asphericity or any difference between front and back lens surface curvatures. The more curved surface of a magnifier should face either the eye or the page, whichever distance is the longer. Instruct the

### Numerical examples to calculate ER

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<tr>
<th>Procedure</th>
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<th>Example 2</th>
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<td>1. Measure the spectacle near addition (F_a), then calculate (f_i = 1/F_a)</td>
<td>+2.5 D</td>
<td>+4.0 D</td>
</tr>
<tr>
<td>2. Determine the optical power of the magnifier (F_m) from its manufacturer's specifications, by (l') focimeter measurement or negative lens neutralisation</td>
<td>E 2655750</td>
<td>E 265570</td>
</tr>
<tr>
<td>3. Determine aperture dimension (by measurement or specification)</td>
<td>A = 75 mm</td>
<td>A = 70 mm</td>
</tr>
<tr>
<td>4. Have the patient hold the magnifier comfortably, then measure lens-to-eye separation (z)</td>
<td>say, 15 cm</td>
<td>say, 12 cm</td>
</tr>
<tr>
<td>5. Subtract (z) from (f_i) to calculate the image distance (-l') for a sharply focused image</td>
<td>0.4 - 0.15</td>
<td>0.25 - 0.12</td>
</tr>
<tr>
<td>6. Calculate (l' = 1/l')</td>
<td>-4.0 D</td>
<td>-7.7 D</td>
</tr>
<tr>
<td>7. Calculate (-l) from equation 1 (= F_m - l')</td>
<td>-14 D</td>
<td>-23.7 D</td>
</tr>
<tr>
<td>8. Calculate ER (= L/l')</td>
<td>3.5 x</td>
<td>3.1 x</td>
</tr>
<tr>
<td>9. Specification of magnification using (F_m/4), so ...</td>
<td>2.5 x</td>
<td>4 x</td>
</tr>
<tr>
<td>10. ... true enlargement ratio is ...</td>
<td>under-estimated</td>
<td>over-estimated</td>
</tr>
<tr>
<td>11. Calculate EVP (F_e) from equation 3</td>
<td>+8.75 D</td>
<td>+12.32 D</td>
</tr>
<tr>
<td>12. Linear field of view (W = A/F_e)</td>
<td>57 mm</td>
<td>47 mm</td>
</tr>
</tbody>
</table>

Table 1. The simple steps in calculating ER and \(W\). This is how we determine whether rated magnification is achieved and whether field of view is adequate.
patient to turn over a hand magnifier to see if image quality in the periphery improves. Although patients may not be able to identify the more curved surface, improvement in image quality at the edge of the field is seen easily.

4. When magnifier-to-page distance is short, advise patients to hold their hand magnifiers as they would hold a spoon. In this way, the side of the palm can rest on the table and support the magnifier steadily at its correct distance. Reading on a wide table stand, 150 mm or so higher than a tabletop, makes closer distances easy to maintain. Rest the upper body on elbows or folded arms when viewing the page on this stand (Figure 4).

5. Teach patients to use magnifiers sitting at a desk or in a chair similar to that in their homes or work environment, when attempting their own tasks, such as reading personal correspondence, sewing or embroidery. Ask patients to bring these tasks to your practice, so that you can demonstrate real improvements in performance.

6. Have patience with people who have low vision. Be understanding of their difficulties in trying to adapt to vision impairment and the new and often unusual reading circumstances that we impose on them when we prescribe magnifiers. Explain to them that the magnifier does not restore normal vision but is an optical device that allows them to use their remaining vision most effectively. Help them adapt to closer viewing distances and slower reading speeds. Encourage them to try again when success is not achieved at first. Despite our careful predictions, how well a patient uses a magnifier depends on its dioptic power, the patient’s need for clear vision, the nature of the task, as well as personal determination and motivation. Several trials may be necessary before a suitable magnifier is chosen.

Optometrists need to understand how simple magnifiers work and why they may not achieve their rated performance levels. As our population ages and vision deteriorates, more patients will seek optometric advice regarding low vision care. Understanding how $z$, $F_a$, and $F$ interact enables us to advise our patients on the efficient use of their magnifiers and be confident that their reading needs will be met.

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