

A review of optical and digital aids for magnification techniques in low-vision rehabilitation

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Abstract

Background: Low vision, a condition characterized by significant visual impairment, poses considerable challenges to individuals' daily functioning and quality of life. Magnification techniques play a pivotal role in mitigating these challenges by enhancing visual acuity and enabling better access to printed materials, digital interfaces, and environmental cues.

Objective: This paper provides a comprehensive overview of magnification strategies employed in low-vision rehabilitation. The review encompasses optical aids, such as magnifiers, telescopes, and microscopic devices, as well as electronic aids, including closed-circuit televisions, screen magnification software, and portable handheld devices. In addition, it explores the integration of magnification techniques with other assistive technologies and adaptive strategies to optimize functional vision. Furthermore, the article discusses emerging trends in magnification technology, including advancements in digital image processing, augmented reality, and wearable devices, which hold promise for further enhancing accessibility and independence for individuals with low vision. **Conclusion:** Understanding the diverse array of magnification options and their applications is crucial for eye care professionals, rehabilitation specialists, and individuals with low vision, enabling them to effectively navigate the visual challenges associated with this condition and promote greater inclusion and autonomy in daily activities.

Keywords: Low vision, Magnification techniques, Optical aids, Electronic aids, Assistive technology

1. Introduction

Low vision is defined as a condition in which the vision in the better eye is <20/60 after standard correction, or a visual field of <20° from the point of fixation.^{1,2} The National Health and Nutrition Examination Survey³ estimated that the prevalence of low vision in the United States was 1.1% in people aged 45 years and above, using a cutoff visual acuity of 6/18. Canadian optometrists also self-reported that approximately 1% of their patients were low-vision patients.⁴ Yekta *et al.*⁵ analyzed prevalence rates from 80 articles drawn from all over the world in individuals under 20 years of age and reported an average index of 1.67% (95% confidence interval [CI], 0.97–2.37%).

The majority of low-vision patients present in the latter stages of ocular morbidity, with males being more likely to

visit the low-vision clinic.⁶ There is also a gap between the availability and uptake of low-vision services worldwide. The

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Submitted: 06 March 2025; Revision received: 23 July 2025;
Accepted: 25 July 2025; Published: 22 August 2025

How to cite this article: Musa M, Enaholo E, Bale BI, *et al.* A review of optical and digital aids for magnification techniques in low-vision rehabilitation. *J Biol Methods*. 2025;12(4):e99010072. DOI: 10.14440/jbm.0002

underrepresented elderly population is a focus of research attention due to their increased vulnerability to age-related visual impairment.⁷ Consequently, their daily activities are affected due to their diminished vision.⁸ The most prevalent functional challenge reported by individuals with low vision is difficulty with reading, and enhancing reading ability often serves as the primary objective of vision rehabilitation interventions, with the potential to positively impact cognitive function.⁹ Through low-vision aids and rehabilitation, patients regain the ability to carry out their daily living tasks by utilizing appropriate optical devices and making necessary environmental modifications to accommodate their residual vision.^{10,11} Hence, when selecting appropriate low-vision aids for visual rehabilitation, consideration is typically given to factors such as age, current visual acuity, disease progression, duration, level of education, and occupation.¹²

Furthermore, alongside the use of low-vision aids, supplementary reading training can enhance reading speed and overall quality of life.¹³ For example, Dickinson *et al.*¹⁴ showed that remote training of individuals suffering from age-related macular degeneration (ARMD) reported a significant improvement in the quality of life and near visual acuity after receiving training. On the other hand, patients with low vision are also more likely to complain about balance and musculoskeletal problems compared to a similar, normally-sighted demographic.¹⁵

2. Importance of magnification in low-vision rehabilitation

Magnification helps to increase both the retinal image size and the angle subtended at the higher visual center. The use of magnification proves to be a beneficial approach in the rehabilitation of individuals with low vision, demonstrating favorable clinical outcomes while also being economically efficient.^{16,17} However, Thomas *et al.*¹⁸ reported a paucity of data on the effectiveness of magnification and low-vision therapy in all age demographics. Nevertheless, when providing glasses and magnifiers for visual rehabilitation to enhance quality of life, it is crucial to explore the financial implications of the intervention for all major stakeholders, including patients, families, and professionals.¹⁹ This consideration is important for patients, as it could potentially improve their visual capabilities.

A study conducted by Latham and Macnaughton²⁰ reported that identifying the print size that low-vision patients find comfortable for reading can serve as an effective indicator for estimating the magnification needed in their rehabilitation process. It is generally more effective to assess and determine their reading speed and critical print size using single sentences rather than paragraphs, except in situations requiring

repeated measurements, such as tracking the progression of a reading disorder or evaluating intervention outcomes.²¹ Granquist *et al.*²² showed that low-vision patients hold prints at closer distances and use larger prints subjectively when reading words as compared to normal-sighted individuals. However, for consistent results, paragraphs are preferred due to their reduced variability. It is important to note that improving reading skills significantly enhances occupational performance, daily activities, and social involvement among the elderly population with low vision.²³ To achieve this, occupational therapy professionals should incorporate the following interventions into their standard care: (i) utilizing stand-based electronic magnification; (ii) providing eccentric viewing training; and (iii) offering comprehensive low-vision services.²⁴

This paper reviews the studies on magnification in low vision published within the past decade to examine the history and innovations in the field. The principles and characteristics of magnification systems are discussed, and the advent of technology in low-vision care is also reviewed.

3. Methodology

The authors used the term “Low-vision magnification” as a search query on the PubMed, reference citation analysis, and Scopus databases. The search algorithm for PubMed was “((“vision, low”[MeSH Terms] OR (“vision”[All Fields] AND “low”[All Fields]) OR “low vision”[All Fields] OR (“low”[All Fields] AND “vision”[All Fields])) AND (“magnification”[All Fields] OR “magnifications”[All Fields])) AND (2014:2024[pdat]).” All retrieved articles were subsequently screened for relevance and formatted by two of the authors (M. Musa and B. Bale). Articles were excluded if they met any of the following criteria: not written in English, lacking a full text or abstract, or irrelevant to the topic. Additional exclusions included articles that did not provide peer-reviewed full text, such as unpublished abstracts or non-peer-reviewed conference proceedings, as well as duplicate entries. Both open-access and subscription-based articles were evaluated to determine if they provided complete content accessible to authors through institutional access or interlibrary loan. A total of 65 papers were thereby excluded, while the remaining 71 papers were reviewed in this paper. A preferred reporting items for systematic reviews and meta-analyses²⁵ chart showing these search criteria is shown in [Figure 1](#).

4. Optical magnification techniques

4.1. Primary magnification techniques

There are three major magnification techniques utilized in low-vision care²⁶;

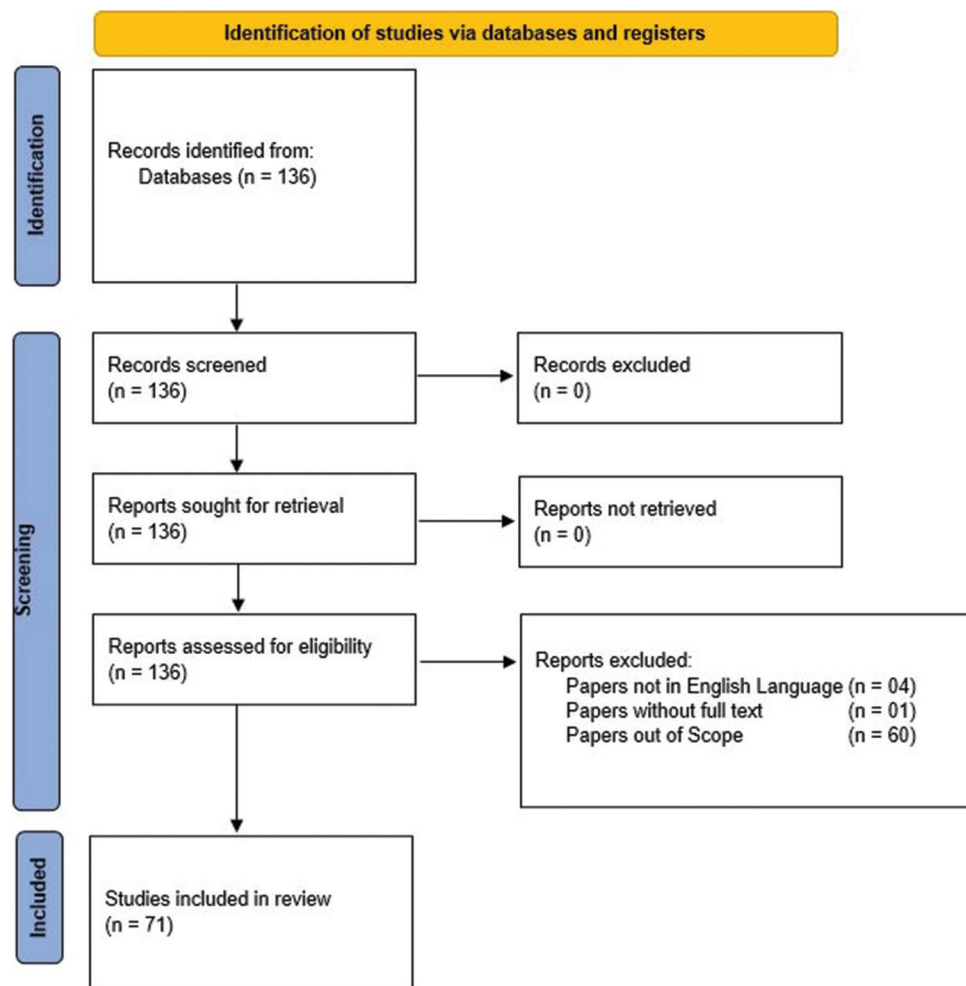


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram for the selection process of papers

4.1.1. Relative size magnification

Here, magnification is achieved by increasing the size of the object viewed, thereby achieving a bigger retina image (Figure 2). This is akin to using a large-print book as opposed to its normal-sized print counterpart. The magnification produced can be derived from Equation I.

$$\text{Relative magnification (m)} = \frac{\text{Secondary object size}}{\text{Primary object size}} \quad (\text{I})$$

4.1.2. Relative distance magnification

Magnification is achieved by bringing the object of regard closer to the patient, making it larger and easier to see (Figure 3). The drawback of this method is that large amounts of accommodation must be present or compensated for with high plus lenses to account for the short working distances. This can be derived from Equation II.

$$\text{Relative magnification (m)} = \frac{\text{Secondary object distance}}{\text{Primary object distance}} \quad (\text{II})$$

4.1.3. Angular magnification

Here, the object of view is not brought closer, nor is its size magnified, but the angle subtended by the image produced by the object is magnified, allowing the higher visual centers to see the target (Figure 4). This can be derived from Equation III.

$$\text{Relative magnification (m)} = \frac{\text{Angle subtended by secondary object}}{\text{Angle subtended by primary object}} \quad (\text{III})$$

4.2. Magnification determination and examples of magnifiers

The magnification required to achieve a task is shown in Equation IV.

$$\text{Magnification} = \frac{\text{Target visual acuity}}{\text{Achieved visual acuity}} \quad (\text{IV})$$

Hence, a patient who sees a final corrected visual acuity of 6/36 and intends to see the 6/9 line will need a $4 \times$ telescope.

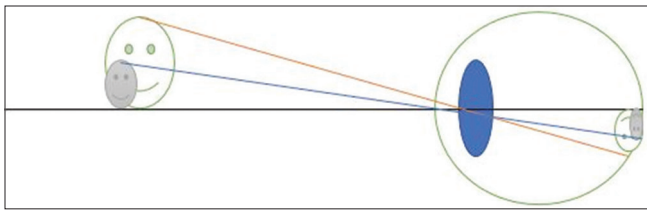


Figure 2. A schematic representation of relative size magnification showing how a bigger object results in a bigger image size. The eyeball is depicted as the large circle surrounding the lens, and the retina is represented by the outline of the eye in the posterior section. The object is the smiley face on the left side of the image. This represents the external object being viewed. The incident light rays are indicated by the orange and blue lines, which project from the object toward and then enter the eye. The blue oval structure in the middle of the eye and the green line in front represent the optical components (cornea and lens) that refract light. The retina (image plane) is shown as the inner surface at the back of the eyeball, where the light rays converge and form an inverted image. The image on the retina is represented as a small, inverted smiley face, which represents the focused image of the object.

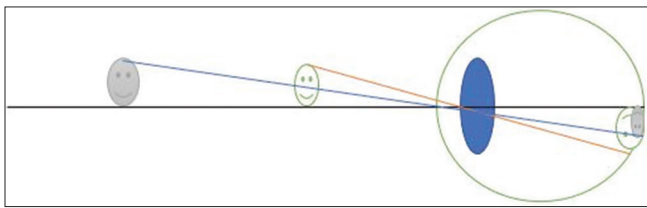


Figure 3. A schematic representation of relative distance magnification showing how a closer object results in a bigger image size. The eyeball is depicted as the large circle surrounding the lens, and the retina is represented by the outline of the eye in the posterior section. The object is the smiley face on the left side of the image. This represents the external object being viewed. The incident light rays are indicated by the orange and blue lines, which project from the object toward and then enter the eye. The blue oval structure in the middle of the eye and the green line in front represent the optical components (cornea and lens) that refract light. The retina (image plane) is shown as the inner surface at the back of the eyeball, where the light rays converge and form an inverted image. The image on the retina is represented as a small, inverted smiley face, which represents the focused image of the object. The grey color indicates that the object is not sharply focused on the retina. The eye is instead focused on the middle green smiley face, which has rays converging perfectly onto the retina.

The same applies to near work, where a patient who wants to read 1 M but has a final corrected visual acuity at near 6 M will need a magnification of 6 ×. Some magnifiers are calibrated in diopters, as opposed to magnification power. However, these can be cross-converted using Equation V.^{27,28}

$$\text{Magnification (M)} = \frac{\text{Power in diopters (F)}}{4} \quad (\text{V})$$

In determining near magnification, Kestenbaum's rule is also sometimes applied. This rule states that the reading add is simply the reciprocal of the distance visual acuity.²⁹ Another study by Engesser *et al.*³⁰ has suggested that when compared to a final low-vision prescription, clinical records alone cannot

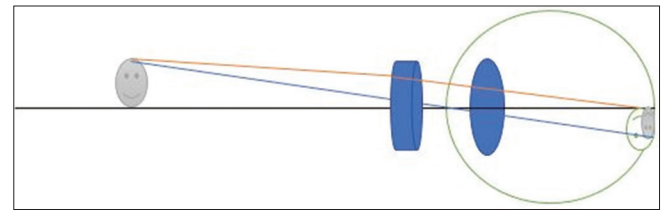


Figure 4. A schematic representation of angular magnification showing how a lens creates a larger angle of resolution and a bigger image size. The use of a corrective convex (plus) lens placed in front of the eye can compensate for a hyperopic (farsighted) optical system. In the uncorrected state, parallel rays from a distant object (represented by the blue line from the grey smiley face) would converge to a point behind the retina, resulting in a blurred retinal image. The corrective lens redirects the incoming light rays so that they are refracted more strongly before entering the eye, allowing them to focus directly on the retinal surface. The grey smiley face represents a distant object that would normally appear out of focus in a hyperopic eye. The additional blue lens in front of the cornea represents a plus lens used for hyperopia correction (*e.g.*, glasses or contact lenses). The orange line depicts how light is refracted by the corrective lens and then further focused by the cornea and crystalline lens. The sharp, inverted image on the retina indicates the correction of refractive error.

correctly estimate the amount of magnification required by a patient. Some magnifiers are displayed in Table 1.

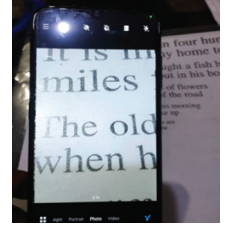
4.2.1. Magnifiers

Magnifiers are typically high-power lenses or systems that help increase the perceived size.³⁷ They operate on the principle of relative size magnification. They can be spectacle magnifiers, handheld magnifiers, stand magnifiers, and telescope magnifiers. The magnifiers can be illuminated or non-illuminated. It should be noted that stand magnifiers are used in conjunction with reading lenses to enable the user to focus the divergent rays that are emitted from this aid.

Multiple factors affect the selection of magnifiers for patients. Particularly, the magnification required by the individual patient, as well as the distance at which this magnifier is to be used. While Table 1 lists several magnifiers for both far and near distances, there is a demographic that requires magnification aids effective at both distances simultaneously. Ambrogi *et al.*³⁸ fabricated a device that facilitated this by capturing distant images and projecting them onto a screen close to the patient, while also magnifying near work. Afinogenov *et al.*³⁹ also designed a device prototype that enabled magnification of both distant and near targets up to 8 times the normal.

The variance of tasks required by low-vision patients leads to the dispensing of a combination of aids/devices after the low-vision assessment. Gobielle *et al.*⁴⁰ reported that low-vision patients may, however, abandon low-vision aids after dispensing, concluding that 29% of them stop using at least one optical assistance within 3 months. One possible reason

Table 1. Magnification devices used in low vision

Type of magnifier	Advantages	Disadvantages	Distance used	Image
Spectacle magnifier ³¹	-Hands-free -Socially acceptable	-Proximity of prints and tasks to the face during use. -Excessive weight of spectacles	Near	
Handheld magnifier ³²	-Socially acceptable -Adjustable magnification -Suitable for domestic tasks	-Limited applicability for individuals with hand tremors	Near	
Stand magnifier ³³	-Fixed object distance -Constant magnified image	-Fixed magnification -Not suitable for writing tasks	Near	
Telescope ³⁴	-Variable focus -Applicable as a field expander (reverse telescope)	-Relatively greater expense than other aids	Distant and near (with a reading cap)	
Hi-tech aids ³⁵	-Applicable as a mounted device -Head-mounted device with improved reading speed ³⁶ -Adjustable contrast to aid vision ³⁷	-Excessive cost	Distance and near	

for this may be the constricted field of view produced by many low-vision devices.⁴¹

Employing magnification as an aid for individuals with low vision enhances their best-corrected visual acuity, both at a distance and near, and also improves their stereopsis. However, the improvement at a distance is not statistically significant.⁴² Johnson *et al.*⁴³ pointed out that social interaction by low-vision patients is hampered by their inability to perceive emotions on the faces of others. Their study, however, concluded that magnification alone will not improve the ability to categorize facial expressions of emotion. Gaze-contingent low-vision aids have been shown to statistically enhance facial recognition and response time in patients with low vision and central field loss, from 41% to 63% (95% CI).⁴⁴

Even with the advent of modern assistive technologies and electronic magnifiers, classic optical magnification remains

a boon to low-vision rehabilitation, including activities of daily living (ADLs) performed at near distances.⁴⁵ Telescopic magnifiers, such as the bioptic, have also been useful in driving.⁴⁶ Care should be taken, however, when driving with the bioptic, as it may also affect the visual field due to the ring scotoma created by the telescope.⁴⁷ The cost of the aid also influences the type of magnifier that patients require. Kyeremeh and Mashige reported that the high cost of low-vision aids was the second-highest barrier preventing the utilization of these aids.⁴⁸

4.2.2. Telescopic systems

Telescopes operate on the principle of angular magnification to bring distant objects into the user’s view. Telescopes can be generally classified as either Keplerian or Galilean.⁴⁹ Keplerian telescopes have plus lenses as the objective and ocular lenses. Galilean telescopes, on the other hand, have

a minus lens as the objective with a plus lens as the ocular. Telescopes can be classified according to multiple factors, as shown in Figure 5.

Telescopic vision aids are mostly indicated for rehabilitating ADLs performed at a far distance.⁴⁶ However, their use can be modified for near function by including the near addition lens power as a focusing cap.²⁷ Monocular telescopes inhibit proper flat fusion; hence, they are not suitable for dynamic tasks. Novel intraocular, implantable, and miniature telescope designs have been associated with good functional adaptation following rehabilitation among patients with marked unilateral central vision impairment/loss.⁵⁰ Bioptic telescopes adapted for specific targets, such as street/road signs, can be more suited to dynamic activity. Galilean telescopes are used for low-vision rehabilitation due to their lower magnification capabilities and subsequent suitability for visual adaptation.⁵¹ High magnification telescopes restrict the total field of view range, and their longer tube lengths can compromise design acceptability.

In albinistic low-vision patients, nystagmus can be a significant problem, causing visual deficits when the eye moves across the surface of a thick lens, as is often the case with handheld, stand-mounted, and spectacle magnifiers.⁵² Although authors have recommended surgery as a palliative measure,⁵³ telescopes are a viable option to improve vision at near distances. Dysli and Abegg⁵⁴ have dissented from this, suggesting that other sensory impairments, such as visual acuity, may be responsible for reading difficulties in people with albinism, rather than nystagmus. Their study found comparable reading speeds when the words were large enough and moved parallel to nystagmic saccades, as observed when comparing people with albinism to healthy subjects.

4.2.3. Microscopic devices

Telemicroscopes are special spectacles equipped with a primary lens that incorporates extra lenses, combined with the near portion.⁵⁵ They can also come as bioptics, where an additional lens is mounted in the distance portion over a primary lens. Telemicroscopes are particularly useful when a patient requires magnification at one distance while maintaining appreciable vision at other distances.⁵⁶ It is therefore used for tasks such as crafting, inspection, and

spot distance viewing. Telemicroscopes are more socially acceptable than telescopes. They are also lighter and easier to use as there is no need for physical handling. This also means that elderly patients with tremors can benefit from them. They are ideal for patients who switch between distance and near vision during their daily activities.

The use of contact lenses in low-vision magnification has gained traction in recent years. Contact lenses offer better weight considerations and cosmetics, in addition to being useful for glare control in patients with albinism and low vision.⁵⁷ Vincent⁵⁸ suggested that the contact lens forms the eyepiece of a telescopic system, while a spectacle lens worn over the eye serves as the objective. Matchinski *et al.*⁵⁹ reported on a case where they used a contact lens as a reading cap, paired with a telescope, to enable a patient to read near print. Theoretically, this can also increase the field of view available to the patient and may be particularly beneficial in patients with already constricted visual fields.⁵⁷

4.2.4. Electronic magnification aids

Electronic magnification aids help magnify objects without the need for physical lenses.⁶⁰ This frees the user from any manipulation or physical activity when using them. The most common type of electronic magnification aid used in low-vision care is the closed-circuit television (CCTV).³⁶ The information generated by the CCTV is not transmitted but rather remains confined to the device itself, ensuring user privacy. The equipment typically consists of an inbuilt camera, an image processor, and a screen.⁶¹ CCTVs offer extended magnifications of up to 100×, reverse polarity, and illumination controls.⁶² One major drawback of CCTV is that its use is difficult to learn, which is further complicated in patients with low vision.⁶³

Individuals with corneal diseases necessitating visual rehabilitation through low-vision aids experience improved reading speed and performance when using CCTV against a dark background, likely due to its ability to minimize luminescence, as suggested by research findings.⁶⁴ Magnification alone may not be sufficient to help every low-vision patient, and activities such as preferential-looking techniques, eccentric fixation, and oculomotor training can be helpful.⁶⁵ Clinicians should ensure that patients participate actively when training to achieve the best results.⁶⁶

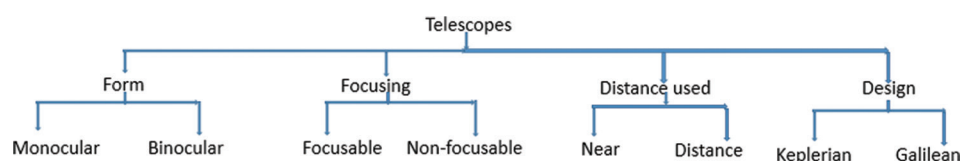


Figure 5. Classifications of telescopes used in low vision

4.3. Role of smartphones and tablets in magnification

With the emergence of smartphones, many daily tasks are now completed on the go using these handheld devices. Da Silva *et al.*⁶⁷ assessed the usability of free magnification apps on the reading characteristics of low-vision patients and concluded that every free app sampled improved reading speed and visual acuity. Conversely, the magnification feature in smartphones has proven beneficial for basic microsurgery training. Nonetheless, its application for this purpose faces challenges regarding its three-dimensional visualization and overall visual clarity.⁶⁸ Numerous software applications are available that can be useful for screen magnification on handheld devices. Some of these are native to the device, while others must be installed. One problem of using the software applications is that the user sometimes gets lost and cannot retrace their view to the initial starting point due to the constricted field of view that comes with magnification. Zoomtext is a software application that enables users to magnify images and print on their devices, while also allowing them to lock scrolling horizontally or vertically, making it easier to return to the starting point.⁶⁹ An additional cutting-edge assistive technology for low-vision rehabilitation is the ArtontheBrain application, which holds promise in making visual art accessible and attainable for leisure, recreation, and therapeutic interventions tailored to individuals with low vision.⁷⁰ Luo⁷¹ developed a smartphone-based magnification app embedded with a sensor algorithm to monitor its use. Activity from over 16,000 individuals from more than 120 states was logged in the study, and the data revealed that the app was used for <3 min a day. A possible reason for this may be the lack of training and awareness of these magnification capabilities among patients who use them.⁷²

Digital devices possess multiple advantages over optical aids, including:

- (i) Digital devices can manipulate the characteristics of the image projected without physically altering the object. Users can invert colors, adjust shade and hue, or selectively highlight text, all to maximize their vision.⁶²
- (ii) Digital devices can offer variable magnification even above and below values that may be out of the limits for standard magnifiers.⁷³
- (iii) Digital devices are more socially acceptable than standard optical aids.⁷⁴

Luo's⁷¹ study suggested that common problems associated with the use of low-vision apps on smartphones included image shaking caused by users' weak grip, which he recommended solving with image stabilization. Morrice *et al.*⁷⁵ further suggested that mobile handheld devices are reasonably comparable to CCTV and other digital devices. In general, smart devices, such as the iPad, have been investigated for their ability to perform comparably to specially designed

video magnifiers.⁷⁶ There are, however, valid concerns that zooming the text on smartphones can greatly restrict the field of view, causing a loss of context for the information being read.⁷⁷ Pundlik *et al.*⁷⁸ piloted a solution to this when they used Google Glass to remotely access the screen of a smartphone, thereby increasing the magnification of texts, and rather than having to zoom in on the handheld and see a few words, users could pan their head from side to side to read the whole text string at once as akin to a book.

5. Integration with assistive technologies

Leveraging smartphones and applications as assistive tools offers magnification and zoom capabilities to aid individuals with low vision, while also facilitating text input and output, as well as command execution through speech features such as Siri and Talkback, which are particularly beneficial for those who are blind.⁷⁹ Because individuals with low vision often encounter challenges when using screen magnifiers to navigate and interact with productivity tools, MagPro presents itself as a user-friendly application interface enhancement, offering an alternative technology that markedly reduces the effort required for panning and zooming.⁸⁰

6. Strategies for maximizing functional vision through technology integration

In a recent preliminary investigation conducted by Bittner *et al.*,⁸¹ it was found that the reading skills and efficiency of individuals with low vision can be enhanced by utilizing tele-rehabilitative technology for training with new magnifiers (including handheld magnifiers, stand optical magnifiers, and portable electronic magnifiers) as opposed to traditional in-office training. Visually impaired users found this videoconferencing technology feasible and acceptable.⁸² Telerehabilitation offers the option for remotely assessing low-vision services instead of in-office training with new magnifiers.⁸³ Novel laser eyewear demonstrated good potential for optimized augmented vision through direct retinal image projection for individuals with disorders affecting the corneal media transparency.⁸⁴

7. Advancements in digital image processing

In clinical applications, remote sensing aided by magnification is currently reported to have advanced to the point where physiological indices, such as heart rate and respiratory rate, can be measured at a distance from a patient.⁸⁵ This potentially means that low-vision patients may accurately assess these important measures in family and loved ones, even in the presence of visual deficits. While the Bubble magnification technique, an electronic magnification method that enlarges a focal area based on gaze direction, can mitigate resolution and

crowding issues, it does not enhance the video comprehension of individuals with central vision loss.⁸⁶ Billah *et al.*⁸⁷ also trialed the SteeringWheel software for helping low-vision patients browse through web pages without losing context due to the magnification of a few words at a time. The software allowed the sampled subjects to simplify the complex browser screens into sections that can be rotated and previewed before being clicked for magnification. Functional vision in reading and visual information processing is enhanced by innovative approaches in magnification, specifically the virtual bioptic telescope and virtual projection screen, which utilize digital image processing within a head-mounted display.⁸⁸

8. Future directions for enhancing accessibility and independence in individuals with low vision

Rehabilitation success depends not only on the choice of suitable magnification equipment but also on organized training programs that facilitate optimal utilization of this equipment. Rehabilitation programs should ideally include task-specific practice, education in eccentric seeing skills, and tactics for contrast enhancement. Moreover, interdisciplinary cooperation among optometrists, occupational therapists, and vision rehabilitation specialists is crucial for customizing interventions that meet the individual’s vocational and social needs. Training must prioritize goal-setting, incremental device integration, and practical simulations to improve skill transferability.

Zhao⁸⁹ suggests that augmented reality (AR) goes beyond traditional magnification, which can be compromised by a constricted field of view and aberrations, and provides low-vision patients with cues that help them achieve daily tasks, such as climbing staircases or navigating crowded spaces. It is crucial to note that AR and wearable magnification devices contain an element of minification for distance vision and magnification for near vision. McLean *et al.*⁹⁰ showed that all minification levels, even as small as 2%, presented with significant discomfort, with no predilection for laterality. Potential users of wearable electronic magnification systems capable of varying angular size magnification may be discouraged from proceeding with device trials due to the

cumbersome appearance of such head-mounted units.⁹¹ It may be worth customizing such vision aids for functional use when performing home-based tasks rather than during public appearances.⁹¹ Table 2 summarizes some articles on the functionality of wearable magnification devices in individuals with visual impairment.

9. Importance of an individualized approach in magnification selection

Several factors influence the acceptability and usability of magnification devices for individuals with low vision. Some of these factors include the patient’s age, the cause of low vision, visual acuity, and the patient’s motivation.⁹⁶ Telescopes are more widely accepted in relatively developed societies compared to less developed communities, where the use of telescopes in public may be associated with stigmatization. The amount of magnification prescribed is also closely related to the condition causing the low vision. Patients suffering from diseases that affect the central visual fields tend to perform better with high magnifications. At the same time, those with peripheral vision conditions, such as glaucoma and retinitis pigmentosa, would likely tolerate lower magnifications. Regarding music enthusiasts, the eSight Eyewear, a head-mounted low-vision rehabilitation device, effectively addresses the magnification challenges encountered by individuals with low vision when reading musical notes.⁹⁷ Its adjustable magnification and hands-free design make it uniquely suited for this task. In addition, factors impacting its usage in low-vision rehabilitation include standardized assessments of device-related quality of life, the absence of headaches associated with its use, and satisfaction with post-usage support services.⁹⁸ The use of wearable electronic vision enhancement systems is known to be complicated by the narrow field rendered by the magnification produced. Researchers have now developed an algorithm to enlarge a part of the text being read while also maintaining a clear view of the surrounding print in fields as small as 10°.⁴⁴

Pundlik *et al.*⁹⁹ developed an optical character recognition-based software that enables users to search for keywords in text or images displayed on a smartphone screen. This

Table 2. Summary of wearable devices for patients with low vision

Author	Device	Type of study	Sample	Outcome
Miller <i>et al.</i> ⁹²	Wearable electronic vision enhancement systems (wEVES)	Randomized controlled trial	32 individuals	wEVES gave image enhancement and better visual acuity
Gopalakrishnan <i>et al.</i> ⁹³	Augmented and virtual reality devices	Original research	100 individuals	Visual acuity and visual field expansion were improved in the sampled population.
Visser <i>et al.</i> ⁹⁴	E-scoop spectacle lens	Randomized controlled trial	190 individuals	The E-scoop spectacle lenses did not yield significant clinical benefits in terms of improving the quality of life, visual acuity, and contrast sensitivity for patients with ARMD.
Cottingham <i>et al.</i> ⁹⁵	Smartphone-assisted head-mounted wearable aid	Original research	18 individuals	Variable magnification yielded favorable subjective improvements in the quality of life of children younger than the age of 10

Abbreviation: ARMD: Age-related macular degeneration.

allows users to zoom in on areas of interest without having to navigate through a cluttered scene. With ARMD being the most common cause of low vision, researchers have achieved better visual acuity using a specialized intraocular lens (IOL) designed to provide enhanced vision in the central 10° as compared to standard IOLs.¹⁰⁰

10. Comparative effectiveness of magnification aids

Although several magnification aids show advantages for those with low vision, direct assessments of their functional effectiveness are scarce. A Cochrane Review by Virgili *et al.*³⁶ demonstrated that electronic video magnifiers provide superior reading speeds compared to optical magnifiers; however, user satisfaction fluctuated according to cost and use. Likewise, randomized controlled studies conducted by Visser *et al.*⁹⁴ assessed E-scoop lenses and demonstrated little improvement in quality-of-life metrics. In contrast, head-mounted digital magnification systems have demonstrated subjective enhancements in pediatric quality of life and improved visual functions in adults with ARMD.^{93,95} This variety in outcomes underscores the importance of matching device type with individual patient objectives and abilities.¹⁰¹

Although magnification tools offer advantages, any detrimental effects must be taken into account. High-powered telescopes and microscopes can induce ring scotomas, create visual distortions, or restrict peripheral awareness, concerns that are particularly significant during walking or driving. Digital devices, although providing freedom, may induce visual strain from screen glare and necessitate cognitive adjustment. Moreover, bulky or prominent wearable gadgets may impede sustained usage due to discomfort or societal stigma. Personalized risk-benefit assessment and user education are essential for alleviating these issues.

11. Conclusion

This paper provides a comprehensive review of the magnification techniques in the context of low-vision rehabilitation. We have explored both optical and electronic aids, discussing their respective advantages, limitations, and applications in various daily tasks. From traditional magnifiers to advanced electronic devices, the array of magnification options offers individuals with low-vision newfound opportunities for independence and engagement in everyday activities.

Moreover, the authors emphasized the importance of integrating magnification aids with other assistive technologies to maximize functional vision and enhance overall quality of life. By leveraging advancements in digital image processing, AR, and wearable devices, the future of

low-vision rehabilitation holds promising prospects for further improving accessibility and autonomy for individuals with visual impairments.

Clinicians are advised to select magnification devices based on assessments of acuity, task-specific requirements, cognitive abilities, and user preferences. Systematic training, risk reduction, and continuous assistance are crucial for effective integration. The impact of emerging technologies, such as wearable digital magnifiers and AR systems, on improving functional outcomes must be evaluated through stringent clinical trials to establish evidence-based guidelines. Through continued research, innovation, and collaboration within the field, we can strive toward a more inclusive society where individuals with low vision can fully participate and thrive in all aspects of life.

Acknowledgments

None.

Funding

None.

Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Not applicable.

References

1. Lee SY, Mesfin FB. Blindness. In: *StatPearls*. Treasure Island, FL: StatPearls Publishing; 2024.

2. Labib TA, El Sada MA, Mohamed B, Sabra NM, Abdel Aleem HM. Assessment and management of children with visual impairment. *Middle East Afr J Ophthalmol*. 2009;16(2):64-68.
doi: 10.4103/0974-9233.53863
3. Chan T, Friedman DS, Bradley C, Massof R. Estimates of incidence and prevalence of visual impairment, low vision, and blindness in the United States. *JAMA Ophthalmol*. 2018;136(1):12-19.
doi: 10.1001/jamaophthalmol.2017.4655
4. Lam N, Leat SJ, Leung A. Low-vision service provision by optometrists: A Canadian nationwide survey. *Optom Vis Sci*. 2015;92(3):365-374.
doi: 10.1097/OPX.0000000000000512
5. Yekta A, Hooshmand E, Saatchi M, et al. Global prevalence and causes of visual impairment and blindness in children: A systematic review and meta-analysis. *J Curr Ophthalmol*. 2022;34(1):1-15.
doi: 10.4103/joco.joco_135_21
6. Chong MF, Jackson AJ, Wolffsohn JS, Bentley SA. An update on the characteristics of patients attending the kooyong low vision clinic. *Clin Exp Optom*. 2016;99(6):555-558.
doi: 10.1111/cxo.12395
7. Trujillo-Tanner C, Caserta MS, Kleinschmidt JJ, Clayton MS, Bernstein PS, Guo JW. Conducting research with older adults with vision impairment: Lessons learned and recommended best practices. *Gerontol Geriatr Med*. 2018;4:2333721418812624.
doi: 10.1177/2333721418812624
8. Trauzettel-Klosinski S. Current possibilities of visual rehabilitation. *Ophthalmologe*. 2018;115(10):895-910.
doi: 10.1007/s00347-018-0767-0
9. Wittich W, Pichora-Fuller MK, Johnson A, et al. Effect of reading rehabilitation for age-related macular degeneration on cognitive functioning: Protocol for a nonrandomized pre-post intervention study. *JMIR Res Protoc*. 2021;10(3):e19931.
doi: 10.2196/19931
10. Sanchez-Gonzalez JM, Rocha-De-Lossada C, Rachwani-Anil R, Castellanos-Gomez I, Alonso-Aliste F. Magnification, yellow filter and prisms low-vision aid in age-related macular degeneration: A case report. *J Fr Ophtalmol*. 2021;44(6):e351-e352.
doi: 10.1016/j.jfo.2020.07.018
11. Wittich W, St Amour L, Jarry J, Seiple W. Test-retest variability of a standardized low vision lighting assessment. *Optom Vis Sci*. 2018;95(9):852-858.
doi: 10.1097/OPX.0000000000001275
12. Das K, Gopalakrishnan S, Dalan D, Velu S, Ratra V, Ratra D. Factors influencing the choice of low-vision devices for visual rehabilitation in Stargardt disease. *Clin Exp Optom*. 2019;102(4):426-433.
doi: 10.1111/cxo.12867
13. Kaltenegger K, Kuester S, Altpeter-Ott E, et al. Effects of home reading training on reading and quality of life in AMD-a randomized and controlled study. *Graefes Arch Clin Exp Ophthalmol*. 2019;257(7):1499-1512.
doi: 10.1007/s00417-019-04328-9
14. Dickinson C, Subramanian A, Harper RA. Evaluating the effectiveness of an established community-based eccentric viewing rehabilitation training model-the evaluation study. *Invest Ophthalmol Vis Sci*. 2016;57(8):3640-3649.
doi: 10.1167/iovs.15-18458
15. Zetterlund C, Richter HO, Lundqvist LO. Visual, musculoskeletal, and balance complaints in AMD: A follow-up study. *J Ophthalmol*. 2016;2016:2707102.
doi: 10.1155/2016/2707102
16. Hernandez-Moreno L, Senra H, Marques AP, Perdomo NM, Macedo AF. The basic VRS-effect study: Clinical trial outcomes and cost-effectiveness of low vision rehabilitation in Portugal. *Ophthalmol Ther*. 2023;12(1):307-323.
doi: 10.1007/s40123-022-00600-0
17. Christen M, Abegg M. The effect of magnification and contrast on reading performance in different types of simulated low vision. *J Eye Mov Res*. 2016;10(2):1-9.
doi: 10.16910/jemr.10.2.5
18. Thomas R, Barker L, Rubin G, Dahlmann-Noor A. Assistive technology for children and young people with low vision. *Cochrane Database Syst Rev*. 2015;2015(6):CD011350.
doi: 10.1002/14651858.CD011350.pub2
19. Hernandez-Moreno L, Senra H, Lewis P, et al. Cost-effectiveness of basic vision rehabilitation (the basic VRS-effect study): Study protocol for a randomised controlled trial. *Ophthalmic Physiol Opt*. 2020;40(3):350-364.
doi: 10.1111/opo.12665
20. Latham K, Macnaughton J. Is patient identification of 'comfortable' print size a useful clinical parameter for low vision reading assessment? *Ophthalmic Physiol Opt*. 2022;42(3):482-490.
doi: 10.1111/opo.12946
21. Kortuem C, Marx T, Altpeter EK, Trauzettel-Klosinski S, Kuester-Gruber S. Comparing reading speeds for reading standardized single sentences and paragraphs in patients with maculopathy. *Ophthalmic Res*. 2021;64(3):512-522.
doi: 10.1159/000509687
22. Granquist C, Wu YH, Gage R, Crossland MD, Legge GE. How people with low vision achieve magnification in digital reading. *Optom Vis Sci*. 2018;95(9):711-719.
doi: 10.1097/OPX.0000000000001261
23. Kaldenberg J, Smallfield S. Occupational therapy practice guidelines for older adults with low vision. *Am J Occup Ther*. 2020;74(2):7402397010p1-7402397010p23.
doi: 10.5014/ajot.2020.742003
24. Smallfield S, Kaldenberg J. Occupational therapy interventions to improve reading performance of older adults with low vision: A systematic review. *Am J Occup Ther*. 2020;74(1):7401185030p1-7401185030p18.
doi: 10.5014/ajot.2020.038380
25. Tonti E, Dell'Omo R, Filippelli M, et al. Exploring epigenetic modifications as potential biomarkers and therapeutic targets in glaucoma. *Int J Mol Sci*. 2024;25(5):28
doi: 10.3390/ijms25052822
26. Woo GC, Mah-Leung A. The term magnification. *Clin Exp Optom*. 2001;84(3):113-119.
doi: 10.1111/j.1444-0938.2001.tb04954.x
27. Aluyi-Osa G, Musa MJ, Zeppieri M. Telescopes. In: *StatPearls*.

- Treasure Island, FL: StatPearls Publishing; 2024.
28. Kaur K, Gurnani B. Low vision aids. In: *StatPearls*. Treasure Island, FL: StatPearls Publishing; 2024.
 29. Sahli E, Idil A. A common approach to low vision: Examination and rehabilitation of the patient with low vision. *Turk J Ophthalmol*. 2019;49(2):89-98. doi: 10.4274/tjo.galenos.2018.65928
 30. Engesser D, Engesser R, Stifter J, Atzrodt L, Bohringer D, Reinhard T. Is the patient record sufficient for prescribing low-vision magnification aids or is a consultation in a low-vision clinic required? *Klin Monbl Augenheilkd*. 2019;236(7):907-910. doi: 10.1055/a-0672-1207
 31. Singh K, Singh A, Chaudury P, Jain D. Efficacy of low-vision devices in elderly population with age-related macular degeneration. *Indian J Ophthalmol*. 2023;71(7):2808-2811. doi: 10.4103/IJO.IJO_72_23
 32. Kaminski JE, Yoshinaga PD, Chun MW, *et al.* Value of handheld optical illuminated magnifiers for sustained silent reading by visually impaired adults. *Optom Vis Sci*. 2023;100(5):312-318. doi: 10.1097/OPX.0000000000002013
 33. Carkeet A. Stand magnifiers for low vision: Description, prescription, assessment. *Clin Exp Optom*. 2020;103(1):11-20. doi: 10.1111/cxo.12948
 34. Doherty AL, Peli E, Luo G. Hazard detection with a monocular bioptic telescope. *Ophthalmic Physiol Opt*. 2015;35(5):530-539. doi: 10.1111/opo.12232
 35. Moshtael H, Aslam T, Underwood I, Dhillon B. High tech aids low vision: A review of image processing for the visually impaired. *Transl Vis Sci Technol*. 2015;4(4):6. doi: 10.1167/tvst.4.4.6
 36. Virgili G, Acosta R, Bentley SA, Giacomelli G, Allcock C, Evans JR. Reading aids for adults with low vision. *Cochrane Database Syst Rev*. 2018;4(4):CD003303. doi: 10.1002/14651858.CD003303.pub4
 37. Monteiro MM, Montilha Rde C, Carvalho KM, Gasparetto ME. Optical and nonoptical aids for reading and writing in individuals with acquired low vision. *Arq Bras Oftalmol*. 2014;77(2):91-94. doi: 10.5935/0004-2749.20140023
 38. Ambrogi N, Dias-Carlson R Jr., Gantner K, *et al.* Low vision system for rapid near- and far-field magnification switching. *Annu Int Conf IEEE Eng Med Biol Soc*. 2015;2015:5012-5015. doi: 10.1109/EMBC.2015.7319517
 39. Afinogenov BI, Coles JB, Parthasarathy S, *et al.* Wearable optical-digital assistive device for low vision students. *Annu Int Conf IEEE Eng Med Biol Soc*. 2016;2016:2083-2086. doi: 10.1109/EMBC.2016.7591138
 40. Gobeille MR, Malkin AG, Jamara R, Ross NC. Utilization and abandonment of low vision devices prescribed on a mobile clinic. *Optom Vis Sci*. 2018;95(9):859-864. doi: 10.1097/OPX.0000000000001267
 41. Jung JH, Kurukuti NM, Peli E. Photographic depiction of the field of view with spectacles-mounted low vision aids. *Optom Vis Sci*. 2021;98(10):1210-1226. doi: 10.1097/OPX.0000000000001790
 42. Sodhi PK, Gautam A, Sharma N, Anand K, Sodhi RS. Role of improved distance and near visual acuity with low vision aids to enhance stereopsis in retinal diseases. *Indian J Ophthalmol*. 2021;69(7):1867-1871. doi: 10.4103/ijo.IJO_3154_20
 43. Johnson AP, Woods-Fry H, Wittich W. Effects of magnification on emotion perception in patients with age-related macular degeneration. *Invest Ophthalmol Vis Sci*. 2017;58(5):2520-2526. doi: 10.1167/iovs.16-21349
 44. Aguilar C, Castet E. Evaluation of a gaze-controlled vision enhancement system for reading in visually impaired people. *PLoS One*. 2017;12(4):e0174910. doi: 10.1371/journal.pone.0174910
 45. Matchinski TL, Crumbliss KE, Corgiat E, Pang Y. Near prescribing trends in two low vision rehabilitation clinics over a ten-year period. *Clin Exp Optom*. 2023;107:563-570. doi: 10.1080/08164622.2023.2246490
 46. Wang S, Moharrer M, Baliutaviciute V, *et al.* Bioptic telescope use in naturalistic driving by people with visual impairment. *Transl Vis Sci Technol*. 2020;9(4):11. doi: 10.1167/tvst.9.4.11
 47. Tang X, Bronstad PM, Doherty AL, *et al.* Hazard detection with monocular bioptic telescopes in a driving simulator. *Transl Vis Sci Technol*. 2020;9(4):26. doi: 10.1167/tvst.9.4.26
 48. Kyeremeh S, Mashige KP. Availability of low vision services and barriers to their provision and uptake in Ghana: Practitioners' perspectives. *Afr Health Sci*. 2021;21(2):896-903. doi: 10.4314/ahs.v21i2.51
 49. Ji YH, Park HJ, Oh SY. Clinical effect of low vision aids. *Korean J Ophthalmol*. 1999;13(1):52-6. doi: 10.3341/kjo.1999.13.1.52
 50. Sasso P, Savastano A, Vidal-Aroca F, *et al.* Enhancing the functional performance of patients with late-stage age-related macular degeneration implanted with a miniature telescope using rehabilitation training. *Ophthalmol Ther*. 2024;13(3):697-707. doi: 10.1007/s40123-023-00871-1
 51. Jolly JK, Sheldon AA, Alvarez I, Gallagher C, MacLaren RE, Bridge H. A low-cost telescope for enhanced stimulus visual field coverage in functional MRI. *J Neurosci Methods*. 2021;350:109023. doi: 10.1016/j.jneumeth.2020.109023
 52. Aquaron R, Lund P, Baker C. [A case for the inclusion of oculocutaneous albinism as a skin-related neglected tropical disease]. *Med Trop Sante Int*. 2023;3(4). doi: 10.48327/mts.v3i4.2023.434
 53. Tegetmeyer H. Treatment options for nystagmus. *Klin Monbl Augenheilkd*. 2015;232(2):174-180. doi: 10.1055/s-0034-1368638
 54. Dysli M, Abegg M. Nystagmus does not limit reading ability in albinism. *PLoS One*. 2016;11(7):e0158815. doi: 10.1371/journal.pone.0158815
 55. Ozen Tunay Z, Idil A, Seza Petricli I, Ozdemir O. Low vision rehabilitation in older adults. *Turk J Ophthalmol*.

- 2016;46(3):118-122.
doi: 10.4274/tjo.68878
56. Harkins T, Maino JH. The BITA telescope: A first impression. *J Am Optom Assoc.* 1991;62(1):28-31.
doi: 10.1109/6.67234
57. Byer A. Magnification limitations of a contact lens telescope. *Am J Optom Physiol Opt.* 1986;63(1):71-75.
doi: 10.1097/00006324-198601000-00011
58. Vincent SJ. The use of contact lenses in low vision rehabilitation: Optical and therapeutic applications. *Clin Exp Optom.* 2017;100(5):513-521.
doi: 10.1111/cxo.12562
59. Matchinski TL, Rimkus JJ, Theisen KM. Case report: Adaptation of a telescope with a minus lens cap for highly myopic patient. *Optom Vis Sci.* 2019;96(6):459-462.
doi: 10.1097/OPX.0000000000001383
60. Jackson ML, Schoessow KA, Selivanova A, Wallis J. Adding access to a video magnifier to standard vision rehabilitation: Initial results on reading performance and well-being from a prospective, randomized study. *Digit J Ophthalmol.* 2017;23(1):1-10.
doi: 10.5693/djo.01.2017.02.001
61. Minto H, Butt IA. Low vision devices and training. *Community Eye Health.* 2004;17(49):6-7.
62. Natarajan S. Low vision aids: A boon. *Indian J Ophthalmol.* 2013;61(5):191-192.
doi: 10.4103/0301-4738.113314
63. Burggraaff MC, Van Nispen RM, Melis-Dankers BJ, Van Rens GH. Effects of standard training in the use of closed-circuit televisions in visually impaired adults: Design of a training protocol and a randomized controlled trial. *BMC Health Serv Res.* 2010;10:62.
doi: 10.1186/1472-6963-10-62
64. Oeverhaus M, Dekowski D, Hirche H, Esser J, Schaperdorth-Gerlings B, Eckstein A. Visual rehabilitation of patients with corneal diseases. *BMC Ophthalmol.* 2020;20(1):184.
doi: 10.1186/s12886-020-01436-7
65. Markowitz M, Daibert-Nido M, Markowitz SN. Rehabilitation of reading skills in patients with age-related macular degeneration. *Can J Ophthalmol.* 2018;53(1):3-8.
doi: 10.1016/j.jcjo.2017.10.042
66. Faubert J, Overbury O. Active-passive paradigm in assessing CCTV-aided reading. *Am J Optom Physiol Opt.* 1987;64(1):23-28.
doi: 10.1097/00006324-198701000-00004
67. Da Silva PBE, Leal AS, Ferraz NN. Usability of smartphone apps as reading aids for low vision patients. *Disabil Rehabil Assist Technol.* 2022;17(7):848-852.
doi: 10.1080/17483107.2020.1820086
68. Lesniewski K, Czernikiewicz K, Zyluk A. An assesment of usefulness of smartphone as a magnifying device for microsurgery training. *Ortop Traumatol Rehabil.* 2019;21(6):457-466.
doi: 10.5604/01.3001.0013.7404
69. Tang M, Manduchi R, Chung S, Prado R. Screen magnification for readers with low vision: A study on usability and performance. *ASSETS.* 2023;2023:23.
doi: 10.1145/3597638.3608383
70. Aubin G, Elalouf K, Hogan M, Altschuler A, Murphy KJ, Wittich W. Usability and accessibility of the artontheBrain™ virtual recreation activity for older adults with low vision due to age-related macular degeneration. *Inquiry.* 2022;59:469580211067446.
doi: 10.1177/00469580211067446
71. Luo G. How 16,000 people used a smartphone magnifier app in their daily lives. *Clin Exp Optom.* 2020;103(6):847-852.
doi: 10.1111/cxo.12996
72. Robinson JL, Braimah Avery V, Chun R, Pusateri G, Jay WM. Usage of accessibility options for the iPhone and iPad in a visually impaired population. *Semin Ophthalmol.* 2017;32(2):163-171.
doi: 10.3109/08820538.2015.1045151
73. Pundlik S, Shivshanker P, Luo G. Impact of apps as assistive devices for visually impaired persons. *Annu Rev Vis Sci.* 2023;9:111-130.
doi: 10.1146/annurev-vision-111022-123837
74. Irvine D, Zemke A, Pusateri G, Gerlach L, Chun R, Jay WM. Tablet and smartphone accessibility features in the low vision rehabilitation. *Neuroophthalmology.* 2014;38(2):53-59.
doi: 10.3109/01658107.2013.874448
75. Morrice E, Johnson AP, Marinier JA, Wittich W. Assessment of the Apple iPad as a low-vision reading aid. *Eye (Lond).* 2017;31(6):865-871.
doi: 10.1038/eye.2016.309
76. Wittich W, Jarry J, Morrice E, Johnson A. Effectiveness of the Apple iPad as a spot-reading magnifier. *Optom Vis Sci.* 2018;95(9):704-710.
doi: 10.1097/OPX.0000000000001269
77. Yeo JH, Bae SH, Lee SH, Kim KW, Moon NJ. Clinical performance of a smartphone-based low vision aid. *Sci Rep.* 2022;12(1):10752-10778.
doi: 10.1038/s41598-022-14489-z
78. Pundlik S, HuaQi Y, Rui L, Peli E, Gang L. Magnifying smartphone screen using Google glass for low-vision users. *IEEE Trans Neural Syst Rehabil Eng.* 2017;25(1):52-61.
doi: 10.1109/TNSRE.2016.2546062
79. Tan HL, Aplin T, McAuliffe T, Gullo H. An exploration of smartphone use by, and support for people with vision impairment: A scoping review. *Disabil Rehabil Assist Technol.* 2024;19(2):407-432.
doi: 10.1080/17483107.2022.2092223
80. Lee HN, Ashok V, Ramakrishnan IV. Screen magnification for office applications. *ASSETS.* 2020;2020:95.
doi: 10.1145/3373625.3418049
81. Bittner AK, Kaminski JE, Ross NC, et al. Telerehabilitation training to facilitate improved reading ability with new magnification devices for low vision. *Optom Vis Sci.* 2022;99(10):743-749.
doi: 10.1097/OPX.0000000000001944
82. Bittner AK, Yoshinaga PD, Shepherd JD, et al. Acceptability of telerehabilitation for magnification devices for the visually impaired using various approaches to facilitate accessibility. *Transl Vis Sci Technol.* 2022;11(8):4.

- doi: 10.1167/tvst.11.8.4
83. Bittner AK, Kaminski JE, Yoshinaga PD, et al. Outcomes of telerehabilitation versus in-office training with magnification devices for low vision: A randomized controlled trial. *Transl Vis Sci Technol.* 2024;13(1):6.
doi: 10.1167/tvst.13.1.6
 84. Stohr M, Dekowski D, Bechrakis N, Oeverhaus M, Eckstein A. Evaluation of a retinal projection laser eyewear in patients with visual impairment caused by corneal diseases in a randomized trial. *Ophthalmology.* 2023;131:545-556.
doi: 10.1016/j.ophtha.2023.11.011
 85. Al-Naji A, Gibson K, Chahl J. Remote sensing of physiological signs using a machine vision system. *J Med Eng Technol.* 2017;41(5):396-405.
doi: 10.1080/03091902.2017.1313326
 86. Costela FM, Reeves SM, Woods RL. An implementation of bubble magnification did not improve the video comprehension of individuals with central vision loss. *Ophthalmic Physiol Opt.* 2021;41(4):842-852.
doi: 10.1111/opo.12797
 87. Billah SM, Ashok V, Porter DE, Ramakrishnan IV. SteeringWheel: A locality-preserving magnification interface for low vision web browsing. *Proc SIGCHI Conf Hum Factor Comput Syst.* 2018;2018:20.
doi: 10.1145/3173574.3173594
 88. Deemer AD, Swenor BK, Fujiwara K, et al. Preliminary evaluation of two digital image processing strategies for head-mounted magnification for low vision patients. *Transl Vis Sci Technol.* 2019;8(1):23.
doi: 10.1167/tvst.8.1.23
 89. Zhao Y. Invited session IV: Extended reality--applications in vision science and beyond: Augmented reality systems for people with low vision. *J Vis.* 2023;23(15):18.
doi: 10.1167/jov.23.15.18
 90. McLean IR, Erkelens IM, Sherbak EF, Mikkelsen LT, Sharma R, Cooper EA. The contribution of image minification to discomfort experienced in wearable optics. *J Vis.* 2023;23(8):10.
doi: 10.1167/jov.23.8.10
 91. Miller A, Macnaughton J, Crossland MD, Latham K. "I'm like something out of star wars": A qualitative investigation of the views of people with age-related macular degeneration regarding wearable electronic vision enhancement systems. *Disabil Rehabil.* 2023;46:4476-4485.
doi: 10.1080/09638288.2023.2278179
 92. Miller A, Macnaughton J, Crossland MD, Latham K. 'Such a lot of bother': Qualitative results of a home trial of a wearable electronic vision enhancement system for people with age-related macular degeneration. *Ophthalmic Physiol Opt.* 2025;45(3):699-712.
doi: 10.1111/opo.13453
 93. Gopalakrishnan S, Chouhan SS, Bhaskaran G, Raman R. Use of augmented reality technology for improving visual acuity of individuals with low vision. *Ind J Ophthalmol.* 2020;68:1136-1142.
doi: 10.4103/ijo.IJO_1524_19
 94. Visser MS, Timman R, Kampen-Smalbrugge J, Buis K, Polling JR, Busschbach JJV. Randomized controlled trial of a spectacle lens for macular degeneration. *Optom Vis Sci.* 2020;97(10):889-897.
doi: 10.1097/OPX.0000000000001588
 95. Cottingham E, Burgum F, Gosling S, Woods L, Tandon A. Assessment of the impact of a head-mounted augmented reality low vision aid on vision and quality of life in children and young people with visual impairment. *Br Ir Orthopt J.* 2024;20(1):57-68.
doi: 10.22599/bioj.345
 96. Lorenzini MC, Wittich W. Factors related to the use of magnifying low vision aids: A scoping review. *Disabil Rehabil.* 2020;42(24):3525-3537.
doi: 10.1080/09638288.2019.1593519
 97. Lussier-Dalpe B, Houtekier C, Duquette J, Wanet-Defalque MC, Wittich W. The challenge of reading music notation for pianists with low vision: An exploratory qualitative study using a head-mounted display. *Assist Technol.* 2022;34(1):2-10.
doi: 10.1080/10400435.2019.1661315
 98. Lorenzini MC, Hamalainen AM, Wittich W. Factors related to the use of a head-mounted display for individuals with low vision. *Disabil Rehabil.* 2021;43(17):2472-2486.
doi: 10.1080/09638288.2019.1704892
 99. Pundlik S, Singh A, Baghel G, Baliutaviciute V, Luo G. A mobile application for keyword search in real-world scenes. *IEEE J Transl Eng Health Med.* 2019;7:2900210.
doi: 10.1109/JTEHM.2019.2935451
 100. Robbie SJ, Tabernero J, Artal P, Qureshi MA. Initial clinical results with a novel monofocal-type intraocular lens for extended macular vision in patients with macular degeneration. *J Refract Surg.* 2018;34(11):718-725.
doi: 10.3928/1081597X-20180831-01
 101. Akpalaba RU, Musa M. Effects of stand magnifiers, hand magnifiers and spectacle magnifiers on reading speed of albinos. *Afscope.* 2007;1:32-42.