A Review of Emerging Technologies for Children with Blindness and Visual Impairment: Opportunities, Challenges, and Future Directions

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ABSTRACT

Purpose: To review emerging technologies that support learning, communication, orientation, mobility, and rehabilitation for children with blindness, visual impairment, and vision loss, with emphasis on tools relevant to educational participation and child development.

Methods: Structured narrative review of PubMed and Google Scholar-indexed literature, prioritizing systematic reviews, randomized trials, interventional studies, and clinically relevant observational research on pediatric low-vision rehabilitation, braille and tactile technologies, smartphone-based accessibility, tele-rehabilitation, orientation and mobility systems, and emerging artificial intelligence applications.

Results: The literature shows that technology is moving from stand-alone specialist devices to flexible, multimodal ecosystems that combine optical enhancement, digital magnification, text-to-speech, audio description, tactile access, smartphone accessibility, wearable sensors, and artificial intelligence. Evidence is strongest for tablets and digital magnification in school access, selected electronic visual aids, and structured rehabilitation programs. AI-enabled tools, including object-recognition and reading systems, show promise for functional independence, but the pediatric evidence base remains limited. Tele-rehabilitation and hybrid service models may extend access, especially where specialist services are scarce, while children with cerebral visual impairment need individualized, developmentally informed interventions.

Conclusions: Newer technologies can improve access to print, participation in classrooms, environmental exploration, and independence, but successful implementation depends on training, affordability, contextual adaptation, and integration within educational and rehabilitation services. Future pediatric research should focus on long-term outcomes, school use, and equitable access.

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Introduction

Childhood blindness and visual impairment remain major global public health and educational concerns as they affect not only visual function, but also literacy, mobility, social participation and development, as well as lifelong educational attainment (1, 2). Currently, the primary challenge extends beyond the provision of magnification devices or braille in isolated settings, and it increasingly involves access to mainstream curricula, digital learning environments, communication platforms, through accessible technologies, that are tailored to children's developmental needs and integrated into everyday family life (2, 3). This shift has significant implications for special education, as technologies now influence how children read, write, navigate, communicate, and participate alongside peers.

Technology provision, however, does not necessarily translate to technology use. School-based studies consistently show that the adoption of assistive technologies is often limited by training deficits, increased cost, maintenance issues, mismatch between devices and tasks, and inadequate support from teachers or rehabilitation teams (4, 5). Therefore, it is important to focus on how technologies can be embedded in child-centered educational plans that promote independence, minimize stigma, and remain usable in real environments such as classrooms, homes, playgrounds, and public spaces (6).

Material and Method

This brief review was designed as a structured narrative review. PubMed and Google Scholar-indexed studies were selected, primarily focusing on systematic reviews, randomized and feasibility trials, observational pediatric studies, and clinically relevant adult or mixed-age studies when pediatric-specific evidence was limited but the technology was directly relevant to child use or to educational planning. The review focused on technologies that support educational access, braille and tactile learning, low-vision enhancement, smartphone accessibility, integration of artificial intelligence (AI), navigation and mobility, and tele-rehabilitation.

Results

The first major theme in the literature pertains to access to printed materials, performance of near-vision tasks such as reading and writing, and access to classroom resources. Cochrane reviews indicate that both assistive technology and optical reading aids benefit children and young people with low vision, but the evidence base has historically been limited and heterogeneous (6, 7). This is why the transition from traditional optical devices to portable digital systems is particularly important, as tablet-based magnification, customizable contrast, variable font sizing, and integrated access to digital content help create a platform capable of serving reading, writing, note-taking, and communication needs in school. The most famous pediatric trial in this field is the randomized study of tablet computers for education and rehabilitation of students with low vision, which showed that mainstream digital devices can support real educational tasks when they are utilized properly (8). Similarly, electronic visual aids used together with perceptual learning can improve visual acuity and functional use in visually impaired children, suggesting that technological means work best when paired with structured rehabilitation rather when they are offered solely as a tool (9). Additionally, head-mounted video display systems and newer low-vision wearables are expanding opportunities for distance viewing, contrast enhancement, and hands-free access, although pediatric-specific data are currently more limited than adult data (10). Overall, these studies support the idea that digital magnification tools are most effective when matched to task demands such as reading from the board, accessing worksheets, and sustaining prolonged near work (8-10).

The second major theme is tactile and braille access; braille remains essential for many children with severe vision loss, especially for literacy, spelling, note-taking, and long-term academic performance. Newer braille technologies include refreshable braille displays, braille note-taking interfaces, and hybrid platforms which allow children to combine braille, audio, and digital text. A recent systematic review found that technology can support braille literacy education in children and youth with visual impairments, particularly when it is integrated with explicit instructions (11). Moreover, mainstream smartphones have emerged as powerful assistive platforms through built-in screen readers, magnifiers, voice control, object recognition, and optical character recognition, and their familiarity can reduce stigma, given that they are devices that already belong everyday social life can support both accessibility and participation, especially for adolescents (12).

Haptic and multisensory technologies represent another promising direction in this field. Virtual haptic environments help blind children explore shapes, spatial relationships, and educational content through structured tactile interaction, thereby supporting concept formation where purely verbal description is not sufficient (13). Such methods are very important for special education since many abstract school concepts, from geometry to maps and science diagrams, heavily depend on spatial representation.

Evidence also shows that technology cannot be separated from developmental rehabilitation. Reviews of early visual intervention have supported that infants and

young children with early-onset visual impairment require timely, individualized, family-centered approaches that link visual stimulation, environmental adaptation, and communication with developmental goals (14). A broader systematic review of interventions for visual impairment found that low-vision device training and structured rehabilitation can improve functioning and participation, however, outcomes vary according to the intervention, age, and subsequent support (15). Practically, this means that technological interventions should be integrated into the child's developmental stage, learning routines, and family capacities.

Newer technologies are especially relevant for children with cerebral visual impairment (CVI). Recent reviews show that interventions for this population include visual stimulation, habilitation methods, task and environmental adaptation, targeted training, and, in some cases, video-game or technology-supported approaches (16, 17). Nonetheless, the evidence remains fragmented, and there is still no universally accepted, evidence-based pediatric protocol for technology-supported intervention in CVI (17). This is important for schools, since several educational technologies designed for ocular visual impairment are not necessarily suitable for children whose primary difficulty involves visual processing, clutter intolerance, latency, or attention (16, 17). Therefore, special education programs need to distinguish clearly between access technologies for ocular low vision and individualized supports for brain-based visual dysfunction.

Another important aspect is service delivery. During and after the COVID-19 period, tele-rehabilitation approaches expanded rapidly, and studies in people with vision impairment demonstrated that remote support may help preserve continuity of care (18). Specifically, visual tele-rehabilitation studies in children with visual impairment suggest that purely remote or mixed models can produce meaningful functional gains (19). For pediatric populations, this has important implications, as tele-rehabilitation improves access to care for families in remote areas, reduces travel burden, and makes training more efficient since therapists are able to work directly within the home or school environment. It is noted that tele-rehabilitation approaches cannot replace in-person assessment when detailed visual evaluation is needed, but can contribute significantly modern pediatric low-vision care (19).

Orientation and mobility technologies constitute another major area of innovation. Systematic reviews of urban navigation systems show that modern assistive mobility tools increasingly rely on sensor fusion, GPS, computer vision, obstacle detection, and mobile connectivity (20). Augmented-reality navigation platforms and multi-sensor tools can improve localization, route guidance, and environmental awareness, especially when they combine multiple data streams to compensate for the limitations of any single sensor (21, 22). These technologies are potentially transformative for children and adolescents, because mobility is foundational for social participation and school inclusion. However, most published studies involve adults, with pediatric training, cognitive load, and safety issues insufficiently explored (21, 22).

AI has revolutionized this trend, since AI and machine learning-driven reading aids and wearable visual assistants are able to recognize text, faces, objects, and colors, in real time. Comparative studies of AI vision aids such as Orcam MyEye and Seeing AI have shown strong performance in reading tasks, especially for flat printed text, although performance worsens with complex layouts or curved surfaces (23). Clinical studies in severe visual impairment demonstrated improvements in reading-related functioning and quality of life, while newer AI-powered smart vision glasses show potential for reading, recognition, and navigation tasks (24, 25). These tools can support classroom participation, independent access to labels and worksheets, and safer exploration of unfamiliar environments in children. Nevertheless, pediatric implementation requires caution given that children need rapid, reliable, and low-latency feedback; as such, systems that are inaccurate, overly verbose, or dependent on network conditions may hinder learning (23-25).

AI should be understood within the broader question of digital accessibility. A recent systematic review of AI and digital accessibility shows that it has enormous enabling potential for people with disabilities, but also raises concerns regarding exclusion, inconsistent accessibility standards, opaque algorithms, and unequal uptake across users and settings (26). For children with blindness or visual impairment, this means that innovation should mainly be judged by accessibility, affordability, privacy, interoperability with school systems, and the extent to which the child can actually learn to use the tool effectively. In this context, earlier reviews of head-mounted display technologies remain relevant because they have shown that promising devices may fail if they produce fatigue, social awkwardness, visual discomfort, or excessive cognitive demand (27).

Discussion

The first message from this review is that visual assistive technology is moving toward convergence. Instead of separate tools for magnification, reading, communication, and mobility, children increasingly use a combination of mainstream devices, specialist interfaces, and cloud-based or AI-enabled functions (4, 8, 23). This convergence is educationally important because it reduces fragmentation, while also increasing the need for structured assessment and collaboration by teachers,

low-vision specialists, occupational therapists, orthoptists, and families (3, 15).
Moreover, the evidence shows that technological means work best when they are embedded within pedagogy and rehabilitation. The strongest pediatric evidence exists for programs in which devices are fitted, taught, practiced, and their use is reviewed over time (3, 8, 9, 15). This is particularly true in CVI, where environmental adaptation and individualized intervention remain central (16, 17). Therefore, special education should view technology as part of a broader habilitation strategy rather than as a stand-alone solution.
Importantly, the evidence base still has important weaknesses and limitations. Many studies have small samples, short follow-up, heterogeneous outcomes, and limited reporting on long-term school performance or psychosocial effects (15-17, 20). The majority of studies on AI wearables and advanced navigation systems have been performed on adults, so direct extrapolation to children warrants caution (20-26). Future research should therefore prioritize pediatric usability, classroom outcomes, literacy trajectories, mobility, family burden, and cost-effectiveness. Considering the rapidly increasing AI use, these priorities are especially urgent to ensure that AI-based methods will become equitable tools for inclusion rather than premium devices available only to a few.
In conclusion, newer technologies for children with blindness, visual impairment, and vision loss have become increasingly capable of supporting access to curriculum, communication, spatial learning, mobility, and independence. The most promising direction points to a multimodal and developmentally informed model in which digital access, tactile literacy, rehabilitation, and AI are integrated into everyday educational life. For clinicians and educators, the key task is selecting technologies that are usable, teachable, and sustainable. For researchers, the next step is to build a stronger pediatric evidence base that measures not only performance in laboratory tasks, but real inclusion in school and community life.

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