Chapter 5
Assistive Technology for Students with Visual Impairments and Blindness

Austin M. Mulloy, Cindy Gevarter, Megan Hopkins, Kevin S. Sutherland and Sathiyaprakash T. Ramdoss

Introduction

The use of assistive technology (AT) with students with visual impairments (VI) and blindness has the potential to improve many student outcomes related to academics and learning (e.g., Bouck et al. 2011; Bowers et al. 2001; Ferrell 2006; Lovie-Kitchin et al. 2001; Spindler 2006; Theoret et al. 2004). Impairments in vision render students with VI and blindness frequently unable to make use of many common objects in schools, such as written instructional materials and computer screens. These impairments also restrict incidental learning opportunities that typically developing students access visually, such as observing others' skill demonstrations and witnessing examples of functional relationships (Hyvarinen 2000). Assistive technologies provide students with VI and blindness access to many school-related activities by enhancing existing sight abilities or drawing on other senses (e.g., hearing) and abilities (e.g., oral language).

A. M. Mulloy (✉)
Department of Educational Psychology Counseling, and Special Education,
The Pennsylvania State University, 125D CEDAR Building, University Park,
PA 16802, USA
e-mail: austin.mulloy@psu.edu

C. Gevarter
Department of Special Education, The University of Texas at Austin, Austin, TX, USA

M. Hopkins
Department of Curriculum and Instruction, The Pennsylvania State University,
University Park, PA, USA

K. S. Sutherland
Department of Special Education and Disability Policy, School of Education,
Virginia Commonwealth University, Richmond, VA, USA

S. T. Ramdoss
Department of Special Education and Communication Disorders,
New Mexico State University, Las Cruces, NM, USA

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This chapter strives to provide examples, explanations, research findings, and implications for use of AT with students with VI and blindness. First, we discuss various definitions of VI and blindness, prevalence of the impairments, common challenges associated with VI and blindness, and the process of fitting AT to students. We then focus on explanations and research findings on AT-relevant assessments of VI and blindness, and AT for pre-academic learning, reading, writing, mathematics, and science students. For each domain of learning, discussions of AT items are grouped according to whether the AT enhances the sight capabilities of users or engages senses and abilities other than sight. Last, we conclude by addressing a number of clinical and academic implications of use of AT with students with VI and blindness, including implications related to assessment, AT selection, teaching and encouraging use of AT, technology abandonment, and future research.

Definitions of Visual Impairment and Blindness

Several different perspectives on VI and blindness have given rise to multiple definitions and conceptualizations of the impairments. These include (a) a focus on the anatomy and etiology of impairments; (b) an emphasis of a person's visual acuity and visual field; and (c) attention to the functional capabilities and limitations of a person's vision. Each approach to defining an impairment is relevant to designing and evaluating AT supports for students with VI and blindness; however, definitions related to visual acuity, visual field, and functional limitations are often most useful to the work of educators (Faye 1996; Individuals with Disabilities Education Improvement Act of 2004 [IDEA] 2004b).

Anatomic and etiological definitions. The medical community has identified a wide variety of disease conditions and anatomical anomalies that lead to VI and blindness (American Foundation for the Blind [AFB] 2013a). These conditions and anomalies can be congenital, meaning they are present at or near the time of a person's birth, or adventitious, meaning they were acquired after birth, during childhood, or some point later. Some of the most common disease conditions and anatomical anomalies include:

1. cortical visual impairment—damage to the visual cortex, temporal lobes, and/or parietal lobes of the brain (e.g., by oxygen deprivation or infections of the central nervous system) which disrupts the receiving and decoding of information sent by the eyes;
2. retinopathy of prematurity—damage to the retina by blood vessel overgrowth and the resulting scar tissue which is associated with premature birth;
3. optic nerve hypoplasia—underdevelopment of the optic nerve, that transmits information to the brain, and possibly midline structures in the brain;

4. strabismus—misalignment of the eyes resulting from abnormal development of eye muscles, nerves which supply the eye muscles, or brain regions controlling eye movement;
5. amblyopia—regression in the function of an eye due to chronic obstruction of vision in the eye, strabismus, or refractive differences between the two eyes;
6. nystagmus—a rapid jiggling back and forth of the eyes that interrupts fixation on objects and which results from underdevelopment of the optic nerve or fovea, or a variety of rod or cone abnormalities (Hatton 2001).

In addition to these conditions and anomalies, VI and blindness can also result as collateral outcomes of traumatic brain injury, severe eye infections, tumors, and diabetes (Geddie et al. 2013).

As mentioned above, the anatomic and etiological factors involved in a person's visual impairment often have little relevance to the design and evaluation of AT supports for students with VI and blindness. The cause of visual loss frequently does not provide information on the residual vision possessed by a person or her ability to make use of vision in functional tasks (Hyvarinen 2000). Further, research has shown that the cause of visual loss is not associated with the degree of delay in developmental milestone acquisitions (Frailberg 1977). However, understanding the anatomic and etiological factors involved in a person's visual impairment can be critically important to the success of treatment initiated by ophthalmologists, optometrists, and neurologists (Matta et al. 2010).

Visual acuity- and visual field-based definitions. The terms *low vision* and *legally blind* are based on measurements of a person's visual acuity and visual field. Visual acuity is an index of the sharpness or clearness of vision (Cline et al. 1997), and is measured by requiring a person to identify symbols on a chart at a distance. The likely familiar 20/20 rating represents nominal vision. A rating of 20/40 implies a person, when at a distance of 20 feet, can identify symbols that a person with nominal vision can identify at a distance of 40 feet. Visual field is the scope of vision (Geddie et al. 2013). Testing of visual field includes measuring the range of a person's central and peripheral visual fields, and results in identification of scotomas (i.e., areas of partially or entirely diminished visual acuity). Normal visual fields are defined as extending roughly 60° toward the nose, 100° away from the nose, 60° upward, and 70° downward (Spector 1990). Individuals are identified as having low vision when they have visual acuity of 20/70 to 20/200 in the better eye after correction (i.e., with eyeglasses or contacts) or a visual field limited to 20–40° after correction (Brilliant 1999). Legal blindness is typically defined as visual acuity of less than 20/200 in the better eye after correction or a visual field limited to less than 20° (Koestler 2004). It's important to note that legal blindness differs from common conceptions of blindness (Huebner 2000). Whereas individuals with legal blindness may have some functional residual vision, individuals identified as blind have either no vision or only the ability to perceive the presence of light.

While use of the labels *low vision*, *legally blind*, and *blind* don't necessarily aid the design and evaluation of AT supports for students with VI and blindness, knowledge of a person's visual acuity, visual field, and extent of light perception can. Generally, when considering a student's ability to perform specific tasks, information regarding visual acuity, visual field, and light perception guides selection of supports for use of residual vision and/or suggests utilization of supports that engage a student's other senses and abilities. The use of information on visual acuity, visual field, and light perception is discussed further throughout the chapter.

Functional categories of visual impairments. Vision impairment can also be conceptualized in terms of functional effects of the involved eye disorder(s) and severity of the impairment. The most useful information for the design and evaluation of AT supports for students with VI and blindness derives from descriptions of the functional effects of eye disorders (Faye 1984, 1996; Hyvarinen 2000; Topor and Erin 2000).

Functional effects of eye disorders. The effects of eye disorders fall into three categories: media pathologies, central visual field defects, and constricted fields or peripheral scotomas (Faye 1984, 1996). Media pathologies produce blurred or hazy vision, reduced contrast sensitivity, and, possibly, increased experience of glare. These effects result from diseases and anatomical anomalies (e.g., cataracts) that affect the optical media (i.e., cornea, pupil, lens, and vitreous). Supports for students with media pathologies should emphasize refraction (e.g., via eyeglasses), control of illumination, and enhancement of contrast. Central visual field defects reduce perception of details and color in the direct line of sight, both at close and far distances. Such defects result from diseases and anatomical anomalies that affect the cone-bearing fovea and macular area of the eyes. Supports for students with central field defects should draw on and maximize peripheral vision through magnification and enhancement of contrast. Constricted fields, or peripheral scotomas, reduce perception of details and color outside the direct line of sight. Notably, constricted fields interfere with orientation in space and cause difficulty in locating objects. When the degree of field constriction is great (i.e., vision is constricted to the cones in the center of the eye), night blindness can result. Such functional effects result from a variety of conditions, such as glaucoma, head trauma, stroke, and retinitis pegmentosa. Supports for students with constricted fields should emphasize magnification and address orientation and mobility needs.

Severity of impairment. Visual impairments are often classified as mild, moderate, severe, or profound; however, no criteria have been put forward for objectively delineating these categories (Bergwerk 2011; Friend 2011). Students with low vision are often considered to have mild to moderate VI. Impairments which qualify as legal blindness can range from moderate to profound, while blindness unarguably constitutes a profound VI. When planning supports for students with VI and blindness, the relative emphasis of AT that enhances vision and AT that draws on other senses and abilities should be in accord with the severity of the student's impairments.

Prevalence of Visual Impairments and Blindness

The prevalence of VI and blindness is estimated at 1 to 5 % of the population (American Academy of Ophthalmology 2002; Mason et al. 2000; Multi-ethnic Pediatric Eye Disease Study Group 2008). The prevalence varies across countries and is generally greater in developing countries, where nutritional disorders (e.g., vitamin A deficiencies) and infections (e.g., trachoma, measles) are common (Geddie et al. 2013). In the United States, determining the actual prevalence is problematic because no comprehensive registry exists and the different databases define VI differently and focus on limited age ranges (Kirchner and Diamant 1999; Mason et al. 2000). For example, the United States Department of Education maintains counts of the number of students who receive special education services by disability category. Students who have multiple disabilities (e.g., blindness and intellectual disability) are counted only once (e.g., as having a VI, an intellectual disability, or multiple disabilities). Students with VI are presumably often counted in categories other than VI, at unknown relative rates. This is particularly problematic for estimating prevalence because between one-third of children with some residual vision and two-thirds of children with blindness have one or more additional disabilities (Kirchner and Diamant 1999; Mervis et al. 2000).

Challenges Associated with Visual Impairments and Blindness

Visual impairments and blindness pose a number of developmental challenges to affected children. The conditions can detrimentally influence physical, cognitive, linguistic, social, and academic development, as well as contribute to the development of problem behaviors (Baillargeon 1993; Bergwerk 2011; Brodsky 2010; Fazzi et al. 1999; Houwen et al. 2010; Hyvarinen 2000; Perez-Pereira and Conti-Ramsden 1999). A variety of factors appear to moderate the effects of VI and blindness on an individual's developmental outcomes. These include the amount of residual vision, the presence and severity of other disability conditions, the overall health of the individual, the amount of support provided to and accepted by the individual, the quality of support provided by teachers, therapists, and parents, and the educational attainment and occupational choices of the individual (Davidson and Quinn 2011; Frailberg 1977; Hatton et al. 1997). Theoretically, by extension, provision of AT supports seems likely to improve students' developmental outcomes.

Challenges to physical development. With regard to physical development, impairments in vision can hinder learning of oculomotor and other motor skills (Bergwerk 2011; Brodsky 2010; Frailberg 1977; Hyvarinen 2000). For example, increases in falling and timidity, especially in new environments, and delays in development of balance, posture, and self-initiated mobility have been observed in infants and toddlers with VI and blindness. Also, many motor skills are typically learned incidentally, via modeling (Brodsky 2010; Hyvarinen 2000). Children with VI and blindness often are unable to utilize such skill demonstrations. Support for development of motor skills in children with VI and blindness is especially important, as decreased motor development in the population is associated with lower levels of physical fitness and higher rates of obesity (Houwen et al. 2010).

Challenges to cognitive development. Children with VI and blindness often experience delayed development of cognition related to spatial concepts (Baillargeon 1993; Hyvarinen 2000). During infancy, children typically develop depth perception and understandings of ego-centric space and object permanence while manipulating objects with their hands and watching the effects of their movements. While many opportunities exist for children with VI and blindness to learn spatial concepts, implementation of supports for early learning is crucial for preventing delays in their cognitive development.

Challenges to linguistic development. Impairments of vision can disrupt and delay the development of preverbal, verbal, and nonverbal language (Brodsky 2010; Perez-Pereira and Conti-Ramsden 1999). The learning of preverbal and nonverbal communication typically involves observation and imitation of others' movements (e.g., of the lips or head). Linguistic development in children with VI and blindness is often instead driven by the sense of hearing. Research has shown that children with VI and blindness use less body and facial language, have difficulty with pragmatics and pronouns (e.g., incorrectly say "you" for "I"), and have less developed conversation skills (Perez-Pereira and Conti-Ramsden 1999). However, children with VI and blindness who have average intelligence or greater often attain typical levels of verbal language proficiency by mid-childhood.

Challenges to social development. With regard to social development, VI and blindness can negatively impact bonding, attachment, and social interaction (Brodsky 2010; Hyvarinen 2000). Much of the bonding and attachment of infants with caregivers is facilitated by eye contact. Similarly, eye contact and vision are central to social interaction and the development of social skills. For example, in a case study of an infant with VI who was delayed in development of social interaction, the provision of eyeglasses immediately resulted in first an expression of surprise, and then a social smile coupled with eye contact (Schwartz et al. 1997). Based on the infant's previous failures to engage socially, the medical professionals working with her had formed the hypothesis that she had an autism spectrum disorder. The results of provision of eyeglasses, however, revealed that the infant's inability to perceive faces had prevented her from developing age-appropriate social behaviors.

Risk of problem behavior. Students with VI and blindness, like many other individuals with disabilities, are at risk for developing problem behaviors (e.g., Conley and Worley 1980; Lalli et al. 1996). For example, children who have impaired night vision may cope with a fear of the dark or inability to navigate independently with behaviors, such as tantruming or screaming, that function to enable their escape from the overwhelming challenges or otherwise aversive stimuli via recruitment of caregivers' assistance (Bergwerk 2011). Individuals with

VI and blindness may also develop atypical self-stimulatory behaviors (e.g., pressing on eyes, waving fingers in front of eyes; Fazzi et al. 1999) or problem behaviors that function to provide access to objects or the attention of others they have difficulty locating or reaching. Such problem behaviors can be successfully extinguished and replaced with functionally-equivalent positive behaviors through behavioral intervention (Alberto and Troutman 2012).

Challenges to academic development. Vision impairments and blindness have the potential to disrupt students' academic learning in traditional, mainstream educational settings. In the past two centuries, many instructional strategies and materials, as well as assistive technologies, have been developed for enabling the learning of students with VI and blindness (Friend 2011). While some students still encounter learning and performance barriers (e.g., in advanced chemistry courses; Supalo et al. 2006), the numbers of these barriers are progressively decreasing with time.

Early detection and intervention with children with VI and blindness is crucial to maximizing their potential for vision and improving their developmental trajectory (Mills 1999; Oldham and Steiner 2010). The current consensus in the medical community is that children pass through a critical period of visual development, lasting from birth to age 6, after which learning of vision skills occurs much less efficiently and the physiological processes of development slow or halt (Groenendaal and Van Hof-Van Duin 1992; Tavernier 1993). Research on early intervention programs corroborates this view; findings suggest treatment success is inversely related to children's age at the time of enrollment (Mills 1999).

Overview of the Process of Fitting Assistive Technologies to Students with Visual Impairments and Blindness

The goals of implementing AT with students with VI and blindness are to increase or improve their functional capabilities, support their education and development, and facilitate their independence (Desch 2013; IDEA 2004c; Sadao and Robinson 2010). Professionals in the field of AT assert these goals can best be achieved by engagement in a standard sequence of procedures for fitting AT to students (e.g., Bryant and Bryant 2003; Cook and Hussey 2002). The process should begin with assessments of the student's skills and abilities, functional limitations, and learning needs, as well as task analyses of activities for which they will receive support. The resulting information should then be used to select AT devices that draw on the student's existing skills and abilities, improve their functional capabilities, and enable their full participation in target activities. When implementing the selected AT, professionals should consult the research literature to identify AT that has the greatest likelihood of effectiveness, take care to obtain the buy-in of the students regarding the AT, confirm use of the AT is convenient and effective, and provide training to the student and others who may support his use of the AT. Finally, periodic and/or on-going evaluations should be carried out regarding the success of implementation of the AT, the device's state of repair, and the goodness of fit among the student's learning needs, skills, functional limitations, and activities for which she needs support. Issues related to assessment, decision making regarding AT, teaching and encouraging use of AT, and evaluation of AT supports are discussed further throughout the chapter.

Research Review

In this section, we provide explanations and research findings on AT-relevant assessments of VI and blindness and AT for pre-academic learning and reading, writing, mathematics, and science students. For each domain of learning, discussions of AT items are grouped according to whether the AT enhances the sight capabilities of users or engages senses and abilities other than sight.

For some AT items discussed below, little or no research has been conducted to investigate or comparatively evaluate devices' effectiveness in improving individual's functional capabilities. Instead, the intuitive appeal of the AT and anecdotes of improved functioning with use of the devices have led to their widespread acceptance and promotion (Hyvarinen 2000). For items for which no research has been conducted, discussion is limited to description of their features and explanation of their potential uses.

Assessment

The extent and quality of assessment are critical determinants of long-term AT implementation outcomes of students with VI and blindness (Day et al. 2001). Research has shown that when one's needs were not fully identified and addressed during the AT assessment and selection process, dissatisfaction with and abandonment of AT are likely (Cook 1982; Zola 1982). To comprehensively document the support needs of students with VI and blindness, and improve the likelihood of student satisfaction and implementation success, professionals from several disciplines conduct assessments of students' visual acuity, visual field, functional use of vision, and preferences for learning media (Faye 1996, 1984; Hyvarinen 2000; Topor and Erin 2000). Results of the assessments are used in planning AT supports, as well as related services, school-based accommodations and curriculum modifications (Friend 2011).

Visual acuity and visual field assessments. As mentioned above, assessment of visual acuity involves requests to identify symbols on a chart at a distance and determines the sharpness or clearness of an individual's vision (Cline et al. 1997). Assessment of visual field involves requests to identify the location of objects in central and peripheral visual fields, and results in identification of scotomas (i.e., areas of partially or entirely diminished visual acuity; Geddie et al. 2013). These types of assessment are performed by medical professionals such as primary care physicians, pediatric neurologists, ophthalmologists, and optometrists. These professionals, as well as certified low vision specialists and teachers of students with VI, use the resulting information to select optical aids to support individuals' use of their residual vision (e.g., eyeglasses, telescopes, closed-circuit television [CCTV]; Faye 1996, 1984; Hyvarinen 2000), plan environmental arrangements (e.g., classroom seating; IRIS Center for Teaching Enhancements 2012), and identify skills for instruction (e.g., how to hold materials at appropriate distances or locations in the visual field; Topor and Erin 2000). To ensure validity of results, professionals who assess students' visual acuity and visual field should use age- and ability-appropriate assessment procedures (Bergwerk 2011; Chou et al. 2011; Committee on Practice and Ambulatory Medicine Section on Ophthalmology, American Association of Certified Orthoptists, American Association for Pediatric Ophthalmology and Strabismus, and American Academy of Ophthalmology 2003; Geddie et al. 2013; Hyvarinen 2000; Topor and Erin 2000; US Preventative Task Force 2011; Utely et al. 1983). For example, consideration should be given to (a) individuals' capacity for cooperation, (b) recognition of symbols, (c) communication of visual experiences, as well as (d) the maturity of the visual system, (e) development of visual behavior (e.g., preferential looking, eye contact), and (f) possible effects of comorbid disabilities. The literature suggests a variety of strategies for addressing challenges to assessment, including (a) use of nonconventional symbols recognized by and meaningful to the student, (b) establishment of fluency with or creation of names for symbols prior to assessment, (c) use of single symbol cards, (d) prompting of alternative responses such as yes/no, gestures, and eye-blinks, (e) engagement of students in interactive tasks (e.g., activating lights in the visual field), (f) assessment of vision in nonconventional, familiar, and/or preferred environments (e.g., a plastic ball pool), (g) segmentation of assessment into a series of short sessions, and (h) use of vision screening technologies (e.g., electroretinogram, electrooculogram, magnetic resonance imaging).

Functional vision assessment. Functional vision assessment evaluates how a student uses vision to complete functional tasks and determines the extent to which the visual disability affects learning (Corn and Webne 2001; Erin 1996; Hyvarinen 2000; Topor and Erin 2000). These assessments are typically performed by teachers of students with VI, who use the results to formulate plans for AT, specialized instruction, and environmental adaptations that increase the efficiency of a student's visual functioning. On occasion, functional vision assessments also uncover needs for additional evaluation(s) related to vision or other functional domains. Of primary interest in the assessment are the questions: (a) what is the range of a student's visual functioning across various lighting, contrast, and color conditions, levels of motivation, and durations of activity?; (b) how does the student function in developmentally appropriate functional tasks and typical, age-specific classroom environments?; and (c) what visual information will need to be compensated for by other modalities? In answering these questions the assessor identifies specific tasks, circumstances, and sensory input for which the student needs support in the form of AT, specialized instruction, and/or environmental adaptations.

Since the environments and abilities of students with VI and blindness vary greatly, no standardized functional vision assessments exist (Shaw et al. 2009). Instead, professionals may use a variety of established instruments or self-developed techniques which involve direct and/or indirect observation, and generate quantitative and/or narrative format results (Bishop 2004; Erin and Paul 1996). While such customization of the assessment process fits the diversity of student profiles and is generally regarded as good practice, no research has investigated the reliability of assessment findings across examiners or varying combinations of assessment methods. As in assessments of visual acuity and visual field, use of age- and ability-appropriate assessment procedures can improve the validity of results (Hyvarinen 2000; Topor and Erin 2000; Utely et al. 1983).

Several authors have published instruments for use in functional vision assessments. These include the Individualized Systematic Assessment of Visual Efficiency (ISAVE; Langley 1998), Functional Vision and Learning Media Assessment (FVLMA; Burnett and Sanford 2008), and Cortical Visual Impairment Range (CVI-Range; Roman-Lantzy 2007). Investigations of the methodological properties of these instruments are limited to assessments of the reliability of the CVI-Range. Newcombe (2010) found the assessment had high internal consistency, test–retest reliability, and inter-rater reliability. When conducting functional vision assessments, professionals may additionally find useful general functioning assessments, such as the International Classification of Functioning, Disability and Health (World Health Organization 2001), Functional Independence Measure for Children (Wong et al. 2005), and the Pediatric Disability Inventory (Ostensjo et al. 2006).

Learning media assessment. Learning media assessment documents a student's preferred sensory channel(s) (i.e., vision, touch, or hearing) and facilitates identification of optimal instructional materials (e.g., pictures, rulers, worksheets), instructional methods (e.g., demonstration, modeling, prompting), and literacy media (e.g., print, Braille) for the student (Koenig and Holbrook 1995). Documentation of a student's sensory channel preferences involves direct observation of the student's interactions with learning media in a variety of settings, recording of observable behaviors, and notation of what sensory channels the student appeared to use in performing the behavior. When data collection is complete, observers make overall tallies of use of each sensory channel and attempt to identify patterns between sensory channel use and features of the environments or activities. Subsequently, the observers or other educational professionals who work with the student peruse extensive lists of instructional materials, instructional methods, and literacy media, organized by the sensory channels each engages, and select media that match the student's identified sensory preferences. Assessment is often re-conducted periodically to determine the adequacy of the learning media implemented with the student.

Authors have published two learning media assessments: the Learning Media Assessment of Students with Visual Impairments (Koenig and Holbrook 1995) and the above-mentioned Functional Vision and Learning Media Assessment (FVLMA; Burnett and Sanford 2008). Assessment materials for each include extensive lists of learning media organized by the sensory channels engaged. The methodological properties of the assessments have not been investigated; however, each has been field tested and experts confirmed they have face validity (American Print House for the Blind 2013; Koenig 1999).

Assistive Technologies for Pre-Academic Learning

As mentioned above, supporting the learning of young children with VI and blindness can improve their academic and functional outcomes at later stages of their education (Groenendaal and Van Hof-Van Duin 1992; Mills 1999; Oldham and Steiner 2010; Tavernier 1993). Theoretically, the development of visual behaviors, haptic awareness, and fine motor skills, and the use of residual vision in play and social interaction enable the learning of more sophisticated and complex functional behaviors and skills in subsequent years. Below, we describe technologies that may support early learning in children with VI and blindness, and the limited research that supports their use.

Technologies that Enhance Sight Capabilities

Toys and adapted play areas. The development of vision, visual behavior, and proprioception in infants is facilitated by manipulation and attending to objects and their hands (Baillargeon 1993; Hyvarinen 2000). Visual impairments may interrupt these developments. To draw infants' attention to objects and their hands, and encourage use of their residual vision, authors have suggested provision of toys that give off light or glow, are marked with bright colors, and/or produce sound (Holbrook 2006; Hyvarinen 2000).

Facial treatments. The development of language in young infants appears to be aided by watching and copying others' lip and tongue movements (Baillargeon 1993; Hyvarinen 2000). Authors have suggested the use of make-up and lighting may improve the ability of infants with VI to perceive others' lip and tongue movements (Holbrook 2006; Hyvarinen 2000). For example, lips can be outlined with a brown contour pen and/or highlighted with lipstick, and light sources can be directed at the face.

Electronic vision enhancement systems. At young ages, children learn to understand pictures as representations of objects (Brandsborg 1996; Hyvarinen 2000). In children with VI, this learning may be disrupted by the use of eyeglasses or other lens-based optical aids, which can result in the division of an image into segments. Perception of only a segment of an image at a given time poses an obstacle to learning in that young children typically do not have the cognitive capability to view segments of an image, recognize their relationships to the whole image, and infer their representation of the whole image.

Electronic vision enhancement systems (EVES), also known as closed-circuit televisions (CCTV) can facilitate the viewing of whole images and have been suggested as supports for children's learning related to picture representations (Hyvarinen 2000). EVES involve video cameras and real-time display of images on screens (Wolffsohn and Peterson 2003). The devices range in size from large desktop units to hand-held devices, and transmit images to TVs, computer monitors, in-built screens, or head-mounted displays. EVES enable variable magnification (e.g., 2X to 60X) and image manipulation (e.g., reversing image contrast, altering colors).

Technologies that Engage Senses and Abilities Other than Sight

Development of haptic awareness and later learning of Braille may be supported by a variety of play items designed to engage children's sense of touch and exercise their haptic awareness (Holbrook 2006; Hyvarinen 2000). For example, research has shown play with textured toys can promote use of the visual cortex for tactile processing in children with VI (Theoret et al. 2004). Also, engagement with Braille readiness books, that present textures and raised shapes and symbols, has been found to improve children's fine motor skills and tactile sensitivity development (Roth and Fee 2011).

Assistive Technologies for Reading

The act of reading is central to many learning tasks in contemporary schools (Atlick 1998; De Castell et al. 1986; Friend 2011). In addition to granting access to educational materials, literacy is a requisite skill for a wide range of work-related, leisure, and life maintenance activities in modernized societies (e.g., Graff 1978; Norris and Phillips 2003). Fittingly, provision and instruction in use of alternative reading materials typically comprise the primary efforts of teachers of students with VI and blindness (Friend 2011; Galvin and Scherer 2004). Below, we describe various technologies that support reading, learning and performance in students with VI and blindness, and when possible, we summarize research on their use.

Technologies that Enhance Sight Capabilities

Large print text. Individuals with low vision may have difficulty viewing small print and making the optical movements required for reading text (American Foundation for the Blind [AFB] 2013f). One possible solution for increasing the readability of text is to use large print (AFB 2013b, f). Large print documents typically make use of font sizes 18 or greater (AFB 2013b; Kitchel 2013). While font size is an important component of large print documents, other factors such as the size of margins and spaces among lines of text, font type, color contrast, number of characters per line, and the distance between the reader and text materials can influence readability and should be manipulated according to the reader's abilities (AFB, 2013f; Kitchel 2013; Lueck et al. 2003). A variety of large print documents such as books, calendars, address books, and labels are commercially available through websites, such as Abledata.com, and print houses, such as American Printing House for the Blind and American Foundation for the Blind. Word processors can also be used to create large print documents for on-screen viewing or for printing (Evans and Blenkhorn 2004).

Research on the efficacy of large print documents has generally demonstrated positive correlations between improvements in reading rates (e.g., words read per minute) and increases in print size for individuals with low vision (Bangor 1998; Lueck et al. 2003; Lovie-Kitchin et al. 2001). Further, visual acuity and age appear to moderate the effects of large print on reading rates (Lovie-Kitchin et al. 2001). For example, Lueck et al. (2003) found the reading rates of fourth graders with low vision tended to decrease with decreases in text size and increase with increases in font size until the diagonal dimensions of letters were about two to four times greater than the individuals' minimum threshold for identification. The researchers hypothesized that the increases in eye and head movements required to read larger fonts prevented further increases in rate. Additionally, participants with relatively better visual acuity had greater increases in rate as text size increased than those with poorer acuity. In another study with students with low vision, ages 7 to 18, the majority of children achieved near normal reading rates with large print sizes (Lovie-Kitchin et al 2001). The study results indicated age and visual acuity were associated with the magnitude of individuals gains in reading rates. To further illustrate, in a study conducted with legally blind students font sizes of text displayed on a computer screen of 12 to 14 were too small to read. However, participants successfully read font sizes of 18, 24, and 30 (Bangor 1998).

While research supports relationships between print size and reading abilities for individuals with VI, studies that compared vision aid use with standard print to large print use alone obtained mixed findings. In a study conducted with legally blind and partially sighted students, test scores on a large print form of a reading test were not substantially higher than scores on a test in font size 10 when optical aids (e.g., magnifiers, glasses) and non-optical aids (e.g., reading lamps and reading stands) were used (Sykes 1971). Measures of reading comprehension and reading rate were not significantly different across conditions, and use of large print was not associated with decreases in reading distances. The partially sighted participants did, however, report less visual fatigue after reading the large print. In contrast, Farmer and Morse (2007) found magnifiers conferred greater benefit than large print documents. Oral reading tests were conducted at the beginning and end of a school year with students with low vision. In reading instruction during the school year, the students received either large print materials or typical sized print materials and magnifiers. Improvements in reading rates were similar between groups. However, while no students in the large print group made substantial gains in reading comprehension, five of the eight students in the magnifier group did. Additionally, case studies conducted by Koenig et al. (1992) involving children with low vision documented that students' reading rates of regular print with optical aids were comparable or superior to reading rates of large print alone. In these case studies, participants reported more positive appraisals of optical aids than large print. The findings of these comparative studies have been corroborated by teacher reports that students who used optical devices achieved higher reading levels than students who used large print materials (Corn 1990).

Researchers concerned with the lack of consistent benefits from use of large print have examined how elements of print appearance in large print documents may affect reading abilities. In the previously discussed study, which evaluated the impact of text size on a computer screens, reading response times and error rates were found to covary with changes in the print's contrast and polarity (Bangor 1998). In another study, increased letter spacing was associated with improved reading speed and decreased minimum font size required by most participants with low vision (McLeish 2007). Also, in research with typically developing children, increased letter spacing led to more improvements in word identification and reading rate than did increased letter size (Hughes and Wilkins 2002).

Despite mixed findings about the benefits of large print text, many individuals with low vision use large print resources. In a survey of adults with low vision in Greece, 28 % reported using large print text "a lot," 9 % used it "quite a lot," while 55 % reported that they never used large print materials (Goudiras et al. 2009). Access to large print documents likely plays a role in the utilization of these resources in schools. In the United States, availability of large print textbooks in schools differs from state to state and district to district (Emerson et al. 2006). Issues such as funding and overall state resources for people with VI and blindness affect availability. For example, some states receive greater quantities of volunteered APH resources and some districts allot more money for textbook purchases. Also, due to production issues (e.g., lack of personnel, insufficient use of technology) large print texts are frequently delivered in an untimely manner and/or may not be available in an individual's needed font size.

Typoscopes. Typoscopes, also called writing guides, are non-optical devices typically made of dark cardboard, plastic, or metal, with cutout spaces that are overlaid lines of writing (AFB 2013h). Although some are specifically designed for writing, the guides are often used to assist students with low vision in reading (Lueck and Heinze 2004). Typoscopes may reduce glare and support readers' scanning across a page and shifting to the beginning of a new line. Typcoscopes may also reduce the minimum print size individuals need to discriminate between letters (Collins 2000).

Although there is limited research on the effectiveness of typoscopes for improving reading, some data suggest they can be helpful. In one study, low vision rehabilitation patients who reported seeing text as “jumbled” or “muddled” were given typoscopes with adjustable windows. Sixty percent of patients initially reported that typoscopes were helpful. Follow up after a year revealed 30 % of patients still used typoscopes on a regular basis and 50 % no longer experienced text as “jumbled” when not using a typoscope (Collins 2000). In another study, students with low vision underwent treatment that included use of reading stands, typoscopes, direct illumination, and/or large print materials (Shaaban et al. 2009). While data were not disaggregated by the type of low vision aids prescribed, the overall improvement in distance and near visual acuity task performance was statistically significant and 76 % of patients reported being satisfied with their low vision aids.

Reading stands. Book or reading stands are display supports that may reduce the physical stress or fatigue experienced by readers with VI who are prone to hold reading materials close or bend over surfaces to view text (Presley and D’Andrea 2009; AFB 2013f). Stands may also be helpful for readers of Braille (Presley and D’Andrea 2009). Varieties of stands are commercially available in portable, desktop, and floor models, and can also be fashioned out of common materials such as a closed, three-ring binder. The selection of an appropriate size and type of stand should be based on the needs of the individual.

The efficacy research which addresses reading stand use is limited. In the previously mentioned study by Shaaban et al. (2009), treatment packages for students with low vision included reading stands. As described above, treatment resulted in improvements in distance and near visual acuity task performance and satisfaction with treatment in 76 % of patients. Also, Gothwal and Herse (2000) analyzed the records of 220 children who received services at a low vision center in India and found reading stands were used in 6 % of treatments and were found acceptable by both parents and children.

Lamps. Improving lighting can be an effective way to make reading tasks easier for individuals with low vision (AFB 2013b; Bowers et al. 2001). Differences in vision profiles warrant careful selection of lighting to match individuals’ needs (AFB 2013b). Any of a variety of common reading lamp bulbs, such as high-wattage, natural light (total-spectrum), compact fluorescent (CFLs), incandescent, and combinations of CFLs and incandescents may be effective reading aids when focused on reading materials. Research which compares bulbs’ effects on reading performance in people with low vision has found no one bulb type stands out as superior (Eperjesi et al. 2007). Effects of a variety of bulbs were found to be statistically similar when results are aggregated across individuals. A large number of commercially available lamps have been designed for individuals with low vision to use for a variety of tasks, including reading (Gerritsen 2001). Popular lamps include variations of the OttLite, a total-spectrum lamp which has bright natural-appearing light, the Reizen Low Vision Floor Lamp, which uses an incandescent bulb that produces minimal glare and a warm hue, and the FD-100 halogen table lamp, which produces strong brightness.

Research suggests lighting enhancements can improve students' reading performance. For example, in a study of individuals with low vision, participants' visual acuity, minimum-required print size, and reading rate all improved at levels of illumination higher than participants' identified illumination preference at the study outset (Bowers et al. 2001). The authors of the study recommended that individual assessments for optimal lighting should consider objective measures of reading ability in addition to subjective ratings of visual comfort and lighting preference.

Despite the potential benefits, many people with VI do not strategically use lighting to improve their reading. In a study of typical reading environments of individuals with VI, 10 % of the reading places used by participants were found to have very high, adequate illumination and 63 % were found to have low, inadequate illumination (Lindner et al. 2001). Single, ceiling light sources were predominant in 60 % of reading locations and additional lights were only present in 40 % of locations.

Lens-based magnification aids. Lens-based magnifiers, such as telescopes and hand-held magnifiers, are task-specific optical aids that enlarge images and allow greater perception in users (Cline et al. 1997; Bowers et al. 2001). In contrast to regular glasses, which are often designed to maximize vision across a variety of contexts and activities, these magnifiers are prescribed for specific activities based on the user's context-related needs. Generally, lens-based magnification aids can be grouped into two categories: near-viewing optical aids and distant-viewing optical aids.

Near-viewing optical aids are used in tasks performed within arm's length, such as reading, writing, drawing, and sewing. Near-view optical aids include stand magnifiers, hand-held magnifiers, and magnifying reading glasses. Each of these aids involves a separate set of utilities and limitations. For example, hand-held and stand magnifiers may be commonly used by students with a variety of visual acuities and visual fields, while each pair of magnifying reading glasses are only useful to students with a particular visual acuity and visual field combination. Stand magnifiers are particularly useful for students with poor motor control due to their fixed position, however, for the same reason, they may be inappropriate for viewing some objects, such as large books. Hand-held magnifiers offer great flexibility in terms of holding distance and location, but the requirement of holding a steady position for reading can lead to fatigue in hands, arms, and/or shoulder muscles.

Distant-viewing optical aids are used in tasks performed at distances greater than arm's length, such as reading a chalkboard, viewing another's skill demonstration, and watching a sporting event. Common distant-viewing optical aids include hand-held and spectacle-mounted telescopes. Similar to above, these aids involve separate utilities and limitations. Hand-held telescopes are highly portable and typically the least expensive. These devices are best for "spot" viewing, such as reading clocks and bus numbers. However, hand-held telescopes require moderate or better motor control and users must remain stationary. Spectacle-mounted telescopes do not require users to remain stationary and circumvent the need for hand coordination and stability. Although, these aids are typically permanently attached to eye glasses and are regarded as unaesthetic.

Research on use of lens-based magnification aids indicates they can improve students' reading rate and comprehension, and facilitate advancements in reading fluency (e.g., Corn 1990; Farmer and Morse 2007; Koenig et al. 1992). However, outcomes have been found to vary across individuals (e.g., Rosenthal and Williams 2000), which suggests identification of the device that will enable the highest levels of reading performance in a student requires trial runs, evaluations, and comparisons with each student.

Electronic magnification aids. As discussed above with regard to AT for pre-academic learning, electronic magnifiers are commonly termed electronic vision enhancement systems (EVES) and closed-circuit televisions (CCTV; Wolffsohn and Peterson 2003). Compared to lens-based magnification aids for reading, EVES may support more natural working distances, better posture, and longer durations and higher rates of reading, as well as protect against light loss (Harper et al. 1999; Mehr et al. 1973; Uslan Shen et al. 1996). However, comparative research has produced conflicting findings. Some work suggests use of lens-based magnification aids is associated with the highest reading outcomes (e.g., Goodrich et al. 1980; Harper et al. 1999), while other studies have found EVES to provide superior support (e.g., Goodrich and Kirby 2001; Stelmack et al. 1991; Watson et al. 1997). Further, research which compares various EVES devices has found outcomes to vary across individuals and devices (e.g., Lusk 2012; Ortiz et al. 1999; Peterson et al. 2003). Taken together, these findings underline the need to conduct evaluations with each individual student during trial runs with a variety of magnification aids before selecting a device.

Technologies that Engage Senses and Abilities Other than Sight

Braille reading materials. Learning to read Braille characters with fingers is a route to literacy that circumvents the limitations of VI and blindness. Braille codes have been created for many languages worldwide using the standard rectangular cell, which contains up to six dots in a 2 by 3 grid (Spungin 1990). Reading materials are typically available in 3 levels of encoding: Grade 1, in which words are fully spelled, Grade 2, which uses abbreviations and contractions, and Grade 3, which involves authors' personal and nonstandard shorthand. The IDEA legislation mandates provision of instruction in and use of Braille with students with VI and blindness unless assessment data suggests an alternative reading media is more appropriate for the student (IDEA 2004a).

Research on the instruction and reading of Braille has documented many positive outcomes, including higher educational achievement and self-esteem, and greater financial self-sufficiency (e.g., Ryles 1997; Schroeder 1996; Stephens 1989). Experts in Braille instruction have argued students in Braille literacy programs should receive between 1.5 and 2 h of literacy instruction per day, as this is the typical amount of time sighted students receive literacy instruction in primary grades (Rex et al. 1994; Koenig and Holbrook 2000). Evidence supports daily Braille literacy instruction. Ryles (1997) found students with legal blindness who received Braille literacy instruction four or five times per week attained significantly and substantially better literacy skills than comparable students who received infrequent instruction.

Braille translation software and computer printers. To convert typical reading or instructional materials to Braille, students with VI and blindness or their teachers can use Braille translation software and computer printers (Disabilities, Opportunities, Internetworking, and Technology Center [DOIT] 2013b; Taylor 2001). Braille translation software recognizes a variety of digital text file formats (e.g., MS Word, PDF, HTML, RTF) as well as allow manual entry of text. The programs convert text to Braille characters in the user-specified language code (e.g., Spanish, English) and encoding grade (i.e., 1 or 2). Common translation software includes Duxbury Braille Translator by Duxbury Systems and Braille 2000 by Computer Application Specialties. Such programs submit Braille character files to special Braille printers, known as embossers. These printers produce raised dot Braille characters on thick paper. Braille embossers vary greatly in price and features. For example, some embossers are capable of producing Braille on both sides of paper (i.e., interpoint Braille), while others print on single sides only. The speed of embossers can range from production of 10 characters to 800 characters per second. High-end embossers can cost over $80,000, while basic versions range between $1,500 and $2,000.

Refreshable braille display. Refreshable Braille displays enable tactual reading of text from computer screens (AFB 2013c). The devices receive output from screen readers (described far below) and produce lines of Braille characters with small pins that raise and lower as the user navigates a screen and encounters text. Refreshable Braille displays can be expensive, however, prices vary greatly based on device features (Braille Note Users 2012). Units differ in the number of refreshable characters (i.e., 20 to 80 Braille cells), note taking and file storage capabilities, compatibility with specific screen readers, input button arrangements, and screen navigational tools. Additionally, some devices only facilitate reading (e.g., PacMate by Freedom Scientific, Focus by Freedom Scientific, Alva by VisonCue), while others enable both reading and Braille input (i.e., note taking; e.g., BrailleNote by HumanWare, Braille Sense by HIMS, and PacMate Omni by Freedom Scientific).

Research on refreshable Braille displays suggests the devices have limitations related to text accessibility and efficiency of use (Kamei-Hannan 2008; Sodnik et al. 2012). Kamei-Hannan (2008) evaluated the accessibility of computer-based language and reading tests. Students who were able to independently operate the devices and associated screen readers (i.e., with speech output disabled) discovered 13 % of the language test questions could not be read due to punctuation (e.g., underlining) that was not translated to Braille. Additionally, the students were unable to comprehend 21 % of the reading test questions due to difficulties related to scrolling through long passages of text. Sodnik et al. (2012) compared use of a refreshable Braille display and screen reader with a novel auditory interface which produced spatially positioned synthetic speech. In observations of a series of reading and information recording tasks, the researchers found the average task completion time was substantially less when participants used the spatial auditory system (i.e., 3 min, 12 s) than when they used the refreshable braille display and screen reader (i.e., 8 min, 38 s). However, no significant differences were found regarding the accuracy of information recorded.

Some research has investigated the use and availability of refreshable screen displays. For example, in a survey of college disability support service coordinators, respondents reported refreshable braille displays were available on only 13.9 % of campuses (Michaels et al. 2002). In another survey of teachers of students with visually impairments and blindness, teachers reported that only 2 % of students used refreshable Braille displays (Abner and Lahm 2002). Authors have hypothesized that the high cost of the devices and the decreasing number of individuals who read Braille has limited the popularity of refreshable Braille displays (Chiang et al. 2005).

Audio format materials. Audio format reading materials enable easy access to content for students with VI and blindness. In recent years, the availability and accessibility of audio books and other reading materials has greatly increased (Majerus 2011). Students with VI and blindness have a variety of options for engaging with audio format reading materials. They may use (a) dedicated audio book players (e.g., Booksense by HIMS), (b) devices that display text and play audio (e.g., Victor Reader Stream by Humanware), (c) multipurpose audio devices (e.g., iPod by Apple), and (d) computer software (e.g., Easy Reader by Dolphin).

Research on audio format materials is limited to a single study. In interviews with students with VI and blindness, Adetoro (2012) found audio format materials were preferred over Braille reading materials by over half of the students due to ease of understanding and playback, and their teachers' ineptitude with Braille.

Screen and document reading software. When students' visual impairments are severe to the degree that they cannot read or cannot efficiently read printed materials or type on computer screens, screen and document reading software may be employed to support access to reading content (AFB 2013e). These softwares allow students to convert text on screens and in documents to synthetic speech (i.e., audio output). To do so, students use a variety of key strokes to undertake actions, such as move about text, read a sentence or paragraph, spell out a word, and identify the location of the cursor. Additionally, the programs allow students to control computer operating systems and applications. In place of the typical visual feedback regarding computer input (e.g., clicking an icon with a mouse cursor opens an on-screen application window), screen and document reading software provides audio feedback (e.g., verbal announcement that an application has opened). Most versions of screen and document reading software allow users to vary several qualities of the synthetic speech, including rate and pitch, as well as to choose from among a variety of language and region-specific accents (e.g., English with a British accent). Common screen and document reading software includes both operating system-based programs (e.g., Narrator for Microsoft Windows Operating Systems, Voiceover for Macintosh Operating Systems) and third-party applications (e.g., JAWS from Freedom Scientific, Kurzweil 3000 by Kurzweil Educational Systems). As mentioned above, some softwares are capable of transferring information to refreshable Braille displays. Additionally, screen and document reading software can grant students with VI and blindness access to printed materials following their scanning and processing with optical character recognition software (e.g., ABBYY FineReader by ABBYY).

Research suggests students with VI and blindness require extensive training and on-going support to independently use screen and document reading software (Earl and Leventhal 1999; Lazar et al. 2007; Leventhal and Earl 1997). For example, students must learn many key strokes for initiating software functions and maintain current knowledge of procedures for accessing new file types, new versions of document applications, and re-organized webpages. Students may also benefit from typing instruction and keyboards adapted for persons with VI and blindness. In survey research with users of screen and document readers with VI and blindness, Earl and Leventhal (1997, 1999) found that a majority of respondents had some form of difficulty with reading tasks attempted in Microsoft applications. They further found 40 % of their sample avoided particular tasks altogether due to the difficulties. Similarly, Lazar et al. (2007) found users of screen and document readers had high levels of frustration in response to confusing speech outputs, software crashes, and incompatibility between the software and various reading documents (e.g., PDF variations).

Assistive Technologies for Writing

Visual impairments and blindness potentiate a number of challenges to students in writing tasks involving typical, visual mediums, such as ink on paper or type on computer screens (AFB 2013d, h; Ponchillia and Ponchillia 1996). In these visual mediums, students with VI and blindness can experience difficulties in learning the mechanics of writing (e.g., punctuation, spelling), taking notes during classes, and engaging in the various phases of composing (e.g., prewriting, drafting, editing) due to limitations of their visual acuity, visual field, and functional use of vision. Below, we describe the variety of AT used to support students with VI and blindness in writing tasks. When possible, we also summarize research on use of the AT.

Technologies that Enhance Sight Capabilities

Paper and writing utensils that provide visual and tactile cues. Individuals with VI may have difficulty with a variety of skills required for writing by hand, such as spacing and placing letters, and following lines (Ponchillia and Ponchillia 1996). Specialized paper and writing utensils that provide sharp contrasts, thick markings, and tactile feedback may aid students' recognition of appropriate locations for writing, increase handwriting legibility (AFB 2013h; Ponchillia and Ponchillia 1996). Paper widely known as "bold-lined paper" has dark, wide lines that may improve recognition of intended writing locations via increased contrast and visual cues. Bold-lined paper, notebooks, and graph paper are available in a variety of colors and line spacing (Russotti et al. 2004). Thick, felt-tip markers (e.g., 20/20 by MaxiAids) are often used in conjunction with bold-lined paper (AFB 2013d). The markers similarly provide high levels of contrast and visual cues, and may support students' formation, placing, and spacing of characters. Individuals who need tactile support for writing by hand may benefit from "raised-line paper" and writing utensils that provide high levels of tactile feedback on writing execution (e.g., HighMark by MaxiAids, Thermalpens by Repro-Tronics; thick, lead, or graphite pencils).

Research on paper and writing utensils that provide visual and tactile cues is limited to one supportive study. A group of Indian researchers who investigated custom intervention packages for students with VI found 80 % of participants who received bold-lined paper and felt-tipped markers considered these particular supports were helpful (Khan et al. 2003).

Typoscopes. As described in the above section on AT for reading, typoscopes are devices typically made of dark cardboard, plastic, or metal, with cutout spaces that are overlaid writing spaces (AFB 2013h; Ponchillia and Ponchillia 1996). Typoscopes may help guide letter formation, spacing, and placement via provision of physical boundaries and contrast. The writing guides may be rigid in construction or flexible, allowing for formation of letters that descend below the interior edge of the typoscope when aligned with the writing line (e.g., "g" or "p"). Some authors suggest flexible typoscopes require greater skill with writing utensils for successful use (AFB 2013d). A variety of typoscopes are commercially available, including writing guides specifically designed for writing checks, letters, and signatures. Additionally, typoscopes may be made out of common materials, such as cardboard.

Technologies that Engage Senses and Abilities Other than Sight

Braille making devices. Students with VI and blindness can make Braille documents with a slate and stylus, Braille typewriters (i.e., Perkins Braillers), or computer systems including Braille embossers, screen and document readers, word processors, and/or Braille translation software (Caton 1991). Braille slates consist of two pieces of metal or plastic attached with a hinge. The front piece contains rows and columns of holes, grouped in Braille cell rectangles (i.e., 2 by 3 hole grids). The back piece contains rows and columns of slight depressions which align with the holes on the front piece when the hinge is closed. Users insert a piece of thick paper between the slate pieces, close the hinge, and then, starting from the right side and moving left, press the stylus (i.e., a blunted bradawl) into the slate's holes to create the raised dots of Braille characters. When finished, users remove the paper from the slate and turn it over to read the Braille characters pushed up from the back side of the paper. Perkins Braillers are manual typewriters that contain six keys, corresponding to the six dots in Braille code, as well as space, line space, and backspace keys. While Braillers are more efficient means of producing Braille characters than use of a slate and stylus, review of what one has written is less convenient. The consensus among teachers of students with VI and blindness is that instruction in Braille literacy should include training with the slate and stylus, beginning in grade 3 or 4, and instruction in use of typewriters, beginning in grades 1, 2, or 3 (Koenig and Holbrook 2000).

Voice recorders. In school settings where accuracy and speed of note taking or writing is important, students with VI and blindness may benefit from making audio voice recordings (e.g., using digital, tape, or other electronic devices; Attmore 1990). Digital voice recorders may also be useful for organizational purposes, such as recording assignments or appointments. A variety of commercially available devices combine voice recording features with word processors (e.g., AudioNote by Luminant Software), word prediction (e.g., Premier Predictor Pro by Premier Assistive Technology), and talking dictionaries (e.g., KeyAccess by Premier Assistive Technology). School districts commonly provide voice recording devices to students with VI and blindness as accommodations for classwork and tests (e.g., Beech 2010).

Speech-to-text software. As an alternative to use of writing utensils and keyboards, students with VI and blindness may prefer to use speech recognition/dictation software that translates speech to text (AFB 2013g). Common speech-to-text programs include Dragon NaturallySpeaking by Next Generation Technologies, MacSpeech Scribe by Nuance, and PlainTalk by Apple (Stefanik 2012). In addition to speech-to-text translation, these programs permit use of voice commands for functions such as opening, editing, and saving computer files. Given speech-to-text programs were not specifically designed for use with screen readers, users of both software types occasionally encounter compatibility problems. Supplemental software, such as J-Say by Next Generation Technologies, can resolve such problems (AbilityNet 2007).

The limited literature on speech-to-text software involves mixed depictions of its utility. Survey research conducted with college-level disability support specialists suggests students with VI and blindness widely and successfully use speech-to-text programs (Michaels et al. 2002). Seventy-three percent of respondents reported they provided the software to students and rated it as moderately to highly useful. However, in a study of use of speech-to-text software by novice, sighted users, researchers found participants had difficulty correcting translation errors and required greater lengths of time for composition compared to when they used keyboards (Karat et al. 1999). These results seem to indicate the development of proficiency with speech-to-text software requires training and practice. Further, Schneiderman (2000) suggested composition with the software involves greater cognitive demands than keyboard use and, thus, may not be appropriate for certain students due to age or disability status.

Text-to-speech software. Talking word processors may support spelling and composition in students with VI and blindness (e.g., Write: Outloud by Don Johnston, Intellitalk by IntelliTools, Read and Write Gold by TextHelp; Angelocci and Connors 2002; Erickson 2004; Nicohls 2013). Students may derive similar support from combined use of typical word processors and screen and document reading software (e.g., JAWS by Freedom Scientific, Kurzweil 3000 by Kurzweil Educational Systems). The talking word processors and screen and document reading software provide auditory review of words as they are typed and allow listening to previously typed text, thus enabling students' recognition of spelling errors (i.e., via the resulting incorrect pronunciation of words) and needs for revisions in compositions. Students with low vision may additionally benefit from the programs' flexibility regarding text size and color, background color, and word highlighting during typing and auditory review. Authors have identified compatibility problems between talking word processors and screen readers related to keystrokes, spelling alerts, and automatic spell checks (Angelocci and Connors 2002).

Spelling and grammar checking software. Students with VI and blindness may obtain support for spelling and grammar from a variety of software programs. Typical word processors, such as MS Word by Microsoft, may be configured to work in conjunction with the JAWS screen reader to detect spelling and grammar errors (Microsoft 2013). Several previously mentioned programs (e.g., Read and Write Gold, Kurzweil 3000, KeyAccess) offer audio output spelling and grammar checking features (Angelocci and Connors 2002). Also, talking dictionaries designed for students with VI and blindness are available as hand-held devices (e.g., Franklin Speaking Language Master Special Edition by Franklin Electronic Publishers) and screen reader-compatible software (e.g., English Talking Dictionary by Premier Assistive Technology).

Survey research with authors with blindness suggests students with VI and blindness stand to benefit from spelling and grammar support (Evans et al. 2003). Respondents in the study reported regular use of spelling and grammar checking software, and indicated needs for such support.

Assistive Technologies for Mathematics

Given that much of the language of mathematics relies on visual reference, learning mathematical concepts can be especially challenging for students with VI and blindness (Jan et al. 1977; Dick and Kubiak 1997). For example, concepts such as direction, quantity, and shape require substantially more cognitive processing when visualization is not possible. Textual and audio supports, such as Braille textbooks and talking calculators, can be useful in facilitating student's access to mathematics materials (Dick and Kubiak 1997), however, tactile support and haptic technology at times offer advantages in the promotion of concrete mathematical understandings in students with VI and blindness (Bussell 2003; Karshmer and Bledsoe 2002). We describe technologies in each of these areas below, and, to the extent possible, research that supports their use.

Technologies that Enhance Sight Capabilities

Interactive whiteboards. Promethean boards and SMART Boards are large-format, interactive whiteboards that display a computer image and allow users to write directly on the screen. There is some evidence that these devices provide specific advantages for students with VI, such as providing users access to the projected image on a screen replicated at their desk (Bosetti et al. 2011), or enlarging text, tables, and graphics that otherwise might not be visible (Scholastic 2013; Smarttech 2005). Moreover, students with light sensitivity are often able to interact with the SMART Board at close distances (Scholastic 2013). Drawing on student and teacher expertise, a recent Illinois State University project offered guidance for using interactive whiteboards with students with VI, such as allowing students to access information displayed on whiteboard screens via devices such as iPads and using the SMART Board to teach students to locate coordinates on a graph (Illinois State University 2012).

Adapted graph paper. As in other subject areas, access to mathematics texts and assessments can be enhanced through large print and graphics (Landau et al. 2003; Willingham et al. 1988). With respect to graphing in particular, given the small-sized boxes and light-colored lines often used for traditional graph paper, graphical items are often inaccessible to students with VI (Royal National Institute of the Blind [RNIB] 2011). Large, bold-lined, or high contrast graph paper may be useful in this regard, and magnifying glasses can be used to supplement mathematics texts (Dick and Kubiak 1997; Landau et al. 2003). This specialized graph paper can be used in combination with pushpins and corkboards, flexible wax strips or felt-tip markers that help to create graphical points, lines, curves, and figures (Dick and Kubiak 1997). In addition, tactile graph paper is available for students with blindness (RNIB 2011).

Technologies that Engage Senses and Abilities Other than Sight

Adapted calculators. A variety of standard and scientific calculators are available that offer modifications for students with VI and blindness, such as large keys, high contrast screens, and Braille input and output (Center for Assistive Technology and Environmental Access [CATEA] 2009). Many accessible calculators also provide auditory output. These talking calculators have been shown to increase computational accuracy and improve efficiency in solving mathematics problems for students with VI (Champion 1976/1977). A recent study of a voice input, speech output (VISO) calculator for use with high school students with VI demonstrated that the tool increased efficiency and fostered greater independence for completing computational problems (Bouck et al. 2011).

In addition to supporting math computational skills, scientific and graphing calculators that include Braille or tactile keyboards and offer auditory output or haptic (i.e., vibratory) feedback may facilitate the learning of more advanced mathematics concepts (CATEA 2009). Examples of calculators or programs that offer auditory support for graphing procedures include the Accessible Graphing Calculator (AGC) and the Sonification Sandbox (Osterhaus 2002; Walker and Lowey 2004). More recent software developments also provide tactile support for graphing and allow students with VI and blindness to convert mathematical data and graphs to tactile forms using a Braille or graphics embosser that connects to the calculator (e.g., the Orion TI-84 Plus; Orbit Research 2013). However, there is little, if any, empirical support for the use of these calculators (Bouck et al. 2011), and systematic study of how to create effective auditory graphics in particular is limited (Walker and Nees 2005). Additionally, both computational and scientific calculators for students with VI have significant limitations with respect to size, price, and availability (Bouck et al. 2011).

Abacus. The abacus is an inexpensive, mechanical tool which may help students with VI and blindness understand mathematical relationships in a non-visual format (Ferrell 2006). Although an abacus can facilitate the learning of foundational-level mathematics, such as addition, subtraction, multiplication, and division, as well as higher-level mathematics, including fractions and decimals, there is conflicting evidence related to its effectiveness with students with VI and blindness. For example, one study showed that an abacus training program improved the computational skills of students with blindness (Nolan and Morris 1964), while another demonstrated that mental calculation and Braille computation were more efficient and accurate than using an abacus (Kapperman 1974).

Math manipulatives. When presenting visual concepts to students with VI and blindness, hands-on experiences with manipulatives can support learning (Belcastro 1993; Dick and Kubiak 1997; La Voy 2009; Osterhaus 2011). Specialized manipulatives designed to meet the needs of students with vision-related disabilities, as well as manipulatives used in mathematics instruction of students without disabilities, may facilitate students' learning of math concepts such as number sense, addition, graphing, and geometry. In fact, the use of concrete mathematical aids is one of just a few evidence-based practices that can increase computation accuracy (Ferrell 2006). Specialized manipulatives may utilize Braille, the Nemeth mathematics code, raised tactile elements (e.g., shapes and textures) or three-dimensional geometric components (Van Scoy et al. 2005). Examples include Tack-Tiles, number blocks, number lines, rulers, dice, counting rods, and algebra tiles (e.g., Belcastro 1993; Bussell 2003; Karshmer and Farsi 2008).

Although a variety of mathematics manipulatives are available for students with VI and blindness, empirical evidence supporting their effectiveness is relatively limited. One small study with first-grade students with blindness demonstrated large effects of using specialized rods for teaching addition and subtraction (Belcastro 1993). The rods were marked with grooves and dimples representing different numbers. Another study, which documented similarly large effects, showed students with VI benefited from the use of a variety of tactile and high-color contrast manipulatives (La Voy 2009). Additionally, two studies focused on college-age students showed use of paper shapes for surfaces and slices of geometrical figures promoted understanding of two- and three-dimensional figures (Spindler 2006), and that cardboard and modeling clay facilitated the teaching of statistical concepts (Gibson and Darron 1999). It is important to note, however, that the integration of audio and haptic support when using manipulatives may better support the learning of math concepts than the use of manipulatives alone (Crossan and Brewster 2008). Despite their potential, mathematics manipulatives are not always provided to or readily available for teachers who work with students with VI and blindness (La Voy 2009).

Tactile graphics. Presentation of information with tactile graphics represents an alternative to visual illustration that draws on haptic perception (Gardner 1996). Several specialized technologies, as well as common crafts materials, can be used to create tactile graphics (DOIT 2013a; Jayant 2006). Specialized technologies include Braille embossers (e.g., The Phoenix embosser by Enabling Technologies), dedicated tactile graphics printers (e.g., the Tiger series by ViewPlus, the Tactile Image Enhancer by Repro-Tronics), tactile displays, and capsule or swell paper and heating devices. Braille embossers allow supplementation of tactile graphics with Braille text, however they are unable to produce high resolution graphics due to their exclusive production of raised dots. Dedicated tactile graphics printers can produce high resolution graphics, although they have limited capabilities to print Braille text. Tactile displays (e.g., the Dot View 2 by KGS) work with software programs (e.g., ChattyInfty by InftyReader Group) to create graphics with a matrix of pins that rise and fall to form shapes and Braille characters. While tactile displays offer the advantages of image scrolling, magnification, reduction, and real-time display, the devices are very expensive. Capsule and swell paper offer the advantage of compatibility with typical computer printers. After printing, the paper is passed through a heating device (e.g., Swell-Form Graphics Machine by American Thermoform Corporation, Picture in a Flash Tactile Graphic Maker by HumanWare) which causes the inked portions to swell and create a raised graphic. Prior to employing these printing methods, a variety of computer software programs can be used to design graphics. Programs that utilize scalable vector graphics, such as Corel Draw, Adobe Illustrator, and Microsoft Word and Powerpoint, are regarded as best for creating tactile graphics due to features which enable customization of line thickness (Van Geem 2012). If these specialized technologies are unavailable or inaccessible, common craft materials, such as glue guns, yarn, and aluminum foil can be fashioned into tactile graphics (Ryles and Bell 2009; Smith and Smothers 2012). Additionally, tactile graphic materials are commercially available in academic resource kits for students with VI and blindness.

Research on tactile graphics supports their use with students with VI and blindness. Evidence suggests students can interpret complex tactile graphics (Campbell 1997) and oral explanations improve their understandings of the illustrated concepts (Krufka and Barner 2006; Schoch 2011). In a comparison of raised line graphics and relief-based graphics, Krufka and Barner (2006) found that raised line graphics are associated with greater concept comprehension than relief-based graphics. In a study of student attitudes toward mathematics, researchers found use of tactile graphics can improve students' appraisals of mathematics courses (Rule et al. 2011). Despite the potential benefits, tactile graphics are frequently not employed. Survey research has found that under half of all teachers of students with VI use tactile graphics with their students (Rosenblum and Amato 2004). The infrequent use may be due to a lack of preparation among teachers to employ tactile graphics in instruction. For example, in a recent survey, 65 % of teachers of students with VI reported they needed more training in creating and teaching with tactile graphics (Rosenblum and Herzberg 2011).

Braille translation software for mathematics. Various computer hardware and software offer support for Braille users' study of mathematics (Cooper 2007; Jayant 2006). Braille representation of numbers and mathematical notations typically involves the Nemeth code. To produce mathematics documents in Nemeth code Braille characters or convert Braille documents for sighted readers, teachers of students with VI and blindness may wish to use translation software for mathematics. Relevant computer hardware and software involve a variety of different processes. Numbers and mathematical notations may be converted from sighted math codes in digital format (e.g., written in MS Word by Microsoft or Scientific Notebook by MacKichan Software) to Nemeth code Braille characters (e.g., with Duxbury Braille Translation or Megadots by Duxbury Systems) and then printed with Braille embossers. For users without sight, creation of sighted math codes and translation to Braille may be aided by screen readers and voice recognition software. Some embossers contain translation software and, thus, remove the need for intermediate translation. For example, the Tiger embosser by ViewPlus can produce Braille documents from files coded in MathType, the mathematics code used in MS Word. Also, OCR programs specifically designed to recognize mathematical expressions, such as InftyReader by InftyReader Group, can be used with translation software to convert scanned documents into Braille code for printing. Finally, users fluent in Braille and the Nemeth code may manually enter characters in Braille note-takers or Braille translation software for conversion into sighted math codes and printing for sighted readers.

Research related to Braille translation for mathematics has addressed the manual translation competencies of teachers of students with VI (DeMario 2000; Rosenblum and Herzberg 2011), the perceived utility of translation hardware and software (Rosenblum and Amato 2004), and the functionality of OCR systems

(Jayant 2006). DeMario (2000), Rosenblum and Herzberg (2011) surveyed teachers of students with VI regarding their self-appraised competencies in manual translation of Nemeth code. Teachers reported to DeMario (2000) that their translation competency decreased and their anxiety in response to translation tasks increased as the complexity of mathematical expressions increased. Rosenblum and Herzberg (2011) found 84 % of teachers in their sample rated their translations as excellent or good. However, two-thirds stated they would benefit from further training in translation for mathematics and 40 % identified themselves as needing additional training. Together, these findings indirectly support use of translation hardware and software as an alternative to manual translation. Survey research on the utility of translation software suggests teachers perceive the systems to have moderate usefulness, and only minor differences exist between the systems' utility (Rosenblum and Amato 2004). In contrast, Jayant (2006) found OCR approaches differ substantially in their functionality (Jayant 2006). The researcher compared use of the InftyReader program, a standard OCR system not specifically designed to recognize mathematical expressions, and use of the two OCR systems in combination, and found the combined use resulted in 15 % greater accuracy of translations.

Assistive Technologies for Science

Similar to the study of mathematics, science courses may present challenges to students with VI and blindness due to the centrality of visually and spatially depicted information (LiveScience 2013; Senge 1998). A variety of technology based supports may support science-related learning in students with VI and blindness. However, very little research has explored their effectiveness in promoting learning. Below, we describe the available technologies and the research that supports their use.

Three-dimensional models. A number of three-dimensional models produced for science courses may be of use in instruction of students with VI and blindness (National Association of Special Education Teachers 2013). Examples include models of human bodies and organs for anatomy lessons, molecule construction kits for chemistry lessons, and models of DNA strands made for biology lessons. Research investigating use of three-dimensional models of cells found that students with VI and blindness made significant gains in identification of cell components (Jones et al. 2006). Further, students reported high levels of interest in the models as instructional tools.

Tactile graphics. Tactile, graphic illustrations of concepts may support learning in science course in students with VI and blindness (Independence Science 2013b). As described above in the mathematics section, various printers, special paper, and material kits for producing tactile graphics are available commercially, and common craft materials, such as glue guns, yarn, and aluminum foil are also useful for creating tactile, graphic illustrations. Several material kits specifically intended for use in science courses are available from the company Independence Science.

Data collection aids. In recent years, Independence Science has released versions of a device called Talking LabQuest, which enables independent participation of students with VI and blindness in a variety of science experiments and learning experiences in field and laboratory settings (Independence Science 2013a; LiveScience 2013). The device is a hand-held, portable computer that includes 70 sensors to measure variables, such as pH, temperature, salinity, and motion. Students operate the device with buttons, the touch screen, or spoken directions. Via a software add-on, called Sci-Voice Access Software, the device provides real-time audio announcement of measurement outcomes. The software allows students to customize the language, pitch, rate, punctuation, and pronunciation of announcements. Additionally, data are stored for later review and analysis.

Personal computer-based laboratory equipment. After collecting data, students with VI and blindness can analyze their data with a program called Logger Pro, by Vernier Software and Technology, which is compatible with screen readers (Independence Science 2013a; Vernier Software and Technology, 2013). The software accepts input from the Talking LabQuest, as well as manual entry of data. Students can use Logger Pro to perform a large variety of analyses (e.g., gas chromatography analysis, data modeling with specified functions), as well as to produce custom graphs and tables.

Clinical and Academic Implications for Use of Assistive Technologies with Students with Visual Impairments and Blindness

Current research and consensus on practice have a number of implications regarding AT for students with VI and blindness. Below, we discuss implications related to assessment, AT selection, teaching and encouraging AT use, technology abandonment, and future research.

Assessment

Given the variety of assessments pertinent to the abilities and support needs of students with VI and blindness, due diligence in assessment necessitates collaboration among professionals from multiple disciplines (Faye 1996; Hyvarinen 2000; Koenig and Holbrook 1995; Topor and Erin 2000). At a minimum, assessment should involve a medical professional, who can examine the student's visual acuity and visual field, and a teacher of students with VI, who can perform a functional vision assessment and learning media assessment. The involvement of professionals from additional disciplines has the potential to increase the utility and extent of the information produced by assessment (Sadao and Robinson 2010; Van Hof and Looijestijn 1995). Organizers of assessments should consider including (a) primary care physicians, (b) pediatric neurologists, (c) opthalmologists, (d) optometrists, (e) certified low vision specialists, (f) teachers of students with VI, (g) other special educators, (h) general education teachers, (i) rehabilitation therapists or counselors, (j) orientation and mobility specialists, and (k) professionals with expertise in treatment of any comorbid disabilities (e.g., occupational therapist).

The value of accurate and valid assessment to subsequent intervention has been repeatedly established in educational and behavioral research (e.g., Al Otaiba 2011; Iwata et al. 1994) and is widely accepted by educational professionals (e.g., IDEA 2004c). As mentioned above, failure to fully identify and address individuals' needs during the AT assessment and selection process is associated with dissatisfaction with and abandonment of AT (Cook 1982; Zola 1982). It is thus safe to assume generation of accurate and valid assessment data facilitates provision of optimal support to students. The issue of accurate and valid assessment is most relevant to preschool age students or those with comorbid intellectual disabilities, multiple disabilities, or autism spectrum disorders (Bergwerk 2011; Chou et al. 2011; Committee on Practice and Ambulatory Medicine Section on Ophthalmology, American Association of Certified Orthoptists, American Association for Pediatric Ophthalmology and Strabismus, and American Academy of Ophthalmology 2003; Geddie et al. 2013; Hyvarinen 2000; Topor and Erin 2000; US Preventative Task Force 2011; Utely et al. 1983). For these students, assessment procedures may need adaptation to yield valid outcomes. Professionals engaged in assessment should consider the degree of fit between assessment procedures and the student's age and abilities other than vision, and contemplate alternative approaches. Consultation with the student's parents, teachers, and other caretakers, as well as other professionals who work with the student can lead to recognition of inappropriate procedures and suitable alternative approaches (Bergwerk 2011; Committee on Practice and Ambulatory Medicine Section on Ophthalmology et al. 2003; Topor and Erin 2000).

Selection of Assistive Technology

In the consideration of AT for a student, the literature suggests best practice comprises (a) matching AT to students' goals and needs, (b) involvement of representatives from multiple disciplines, (c) provision of complimentary supports, (d) initial and on-going evaluation of AT implementation outcomes, and (e) sensitivity to students' cultural norms and preferences. Given the purposes of AT for students with VI and blindness are to increase or improve their functional capabilities, support their education and development, and facilitate their independence

(Desch 2013; IDEA 2004c; Sadao and Robinson 2010), AT selected for a student should match their needs for support in functional tasks and enable attainment of goals for education and development (Bryant and Bryant 2003; Cook and Hussey 2002; Topor and Erin 2000). Professionals engaged in the selection of AT for a student may find it useful to augment assessment findings on the student's abilities and support needs with information on students', parents', teachers', and other caretakers' expectations and goals for the student's functioning. Doing so may involve interviews, review of Individualized Education Program documents for the student, or formal instruments, such as the Expectations for Visual Functioning (Corn and Webne 2001).

Given the diversity of technical expertise required for assessment and interpretation of data on the abilities and support needs of students with VI and blindness, the brainstorming of possible AT solutions may benefit from the involvement of representatives from multiple disciplines (Faye 1996; Hyvarinen 2000; Koenig and Holbrook 1995; Sadao and Robinson 2010; Topor and Erin 2000; Van Hof and Looijestijn 1995). For example, optometrists have unique expertise in refraction-based solutions (e.g., eyeglasses), certified low vision specialists and teachers of students with VI likely have unique expertise in non-optical aids for vision, and the student's teachers and parents likely have unique insights regarding the practicality of implementing various forms of AT. Further, the complementarity of AT selected for a student can be improved by including professionals from multiple disciplines (Hyvarinen 2000). For example, for certain students use of refractive magnifiers can problematically reduce the contrast of reading materials (Cline et al. 1997). Should a teacher suggest use of a magnifying glass due to its practicality, an optometrist could add the suggestion of outfitting the magnifying glass with a colored film that enhances the contrast of reading materials. Also, students with comorbid disabilities may require multiple, complementary supports (e.g., vision, head position, and posture supports for students with multiple disabilities; Friend 2011). In such cases, collaborations among professionals, such as optometrists, occupational therapists, and teachers are likely to lead to more effective and practically feasible solutions.

Conducting initial and on-going evaluations of the use of AT with students facilitates determination of the adequacy of a student's supports (Alberto and Troutman 2012; Bryant and Bryant 2003; Cook and Hussey 2002). Since no structured system exists for the selection of AT and implementation results vary from person to person, the process typically begins with educated guesses as to what would produce benefit for the student, based on review of assessment results and the professionals' prior experiences (Desch 2013). Evaluation of the adequacy of identified AT and related supports should follow this guesswork. The evaluation process should start with collection of baseline data on the student's present levels of functioning. Subsequently, data should be collected during test runs performed in all settings in which the student will use the AT, to confirm the AT and any additional supports provided are adequate. After making any adaptations to the support plan and performing additional test runs, on-going evaluations should be maintained to monitor the success of implementation and emergent needs of the student. Use of single-subject research design methodology (e.g., operational definitions of behavior, behavior counts, multiple baselines across settings) can promote objectivity in evaluations (Kennedy 2005).

A final set of issues to consider in the selection of AT for students with VI and blindness are their cultural norms and preferences (Sadao and Robinson 2010). Across culture groups, norms and preferences may vary with regard to visual behavior, play, care, and children's rights (e.g., Salend and Taylor 2002; Xie 2009). To respond to a student's culture and arrive at socially valid intervention plans, professionals should engage families and students in the processes of intervention plan development and implementation of AT.

Teaching and Encouraging Use of Assistive Technology

To encourage students' use of AT, professionals, parents, and other caregivers should (a) use evidence-based methods to teach and support skills for AT use, (b) include goals and objectives for AT use in the students' IEPs, (c) integrate intervention into students' preferred functional activities, and (d) provide complimentary services that support the students' AT use. Many forms of AT for students with VI and blindness require specific skills for successful use. On-going use of evidence-based methods for teaching and behavior support, such as direct instruction, practice with feedback, shaping, and reinforcement of success, provides the greatest likelihood students will acquire the requisite skills and maintain the related behaviors (Alberto and Troutman 2012; Archer and Hughes 2011; Sadao and Robinson 2010). To bolster efforts to teach skills for use of the AT, a student's IEP committee should include goals and objectives for AT use in his/her IEP (Geddie et al. 2013; Friend 2011; Presley 2010). The potential value of doing so derives from the committee's articulation of what successful implementation of the AT will include, commitment to on-going implementation and monitoring of outcomes, and delineation of responsibilities for adapting the intervention plan as necessary. Students' success in use of AT may be enhanced by integrating intervention into students' preferred functional activities (Topor et al. 2004; Lueck and Heinze 2004) and providing complimentary services (Cochrane et al. 2011; Ferrell 1996, 1985; Tavernier 1993; Topor and Erin 2000). Integration of intervention into preferred functional activities can facilitate the student's access of established and preferred reinforcers, which may lead to increased use of the AT in the activity context and beyond. Provision of complimentary services, such as medical treatment, behavioral optometry/vision instruction, adaptation of the physical environment, and orientation and mobility training, may enhance a student's visual functioning and improve outcomes of AT use, thereby enabling increased access to natural reinforcers for AT use.

Technology Abandonment

Roughly one-third of all recipients of AT have been found to abandon their devices (Phillips and Zhao 1993). As stated above, abandonment of AT is associated with reports that one's needs were not fully identified and addressed during the AT assessment and selection process (Cook 1982; Zola 1982). Frequently cited reasons for AT abandonment have specifically included complaints that (a) the AT did not enable satisfactory improvements in functioning, (b) use of the AT was inconvenient, awkward, and/or socially stigmatizing, and (c) the AT was not relevant to personal goals for improved functioning (Cook 1982; Day et al. 2001; Phillips and Zhao 1993; Zola 1982). Professionals may be able to decrease the likelihood of AT abandonment by making efforts during assessment, AT selection, and phases of teaching and supporting AT use. For example, to maximize the potential for improvements in functioning, professionals can (a) conduct initial evaluations of the AT's appropriateness and the student's functioning with the AT in all settings targeted for use prior to committing to implementation (Alberto and Troutman 2012; Bryant and Bryant 2003; Cook and Hussey 2002), (b) provide support for the student's use of the AT with fidelity to the plan established (e.g., in the student's IEP; Geddie et al. 2013; Friend 2011; Presley 2010), (c) conduct on-going evaluations of the AT's appropriateness and the student's functioning with the AT, and, if relevant, consider alternative forms of AT and/or additional training and support for use of the AT (Alberto and Troutman 2012; Bryant and Bryant 2003; Cook and Hussey 2002), and (d) provide treatment for any comorbid disabilities or disorders to attenuate their impact on the student's functionality and use of the AT (Levack et al. 1994). To reduce any inconvenience, awkwardness, or social stigma involved in AT use, professionals can (a) monitor these factors in initial and on-going evaluations of the student's functioning with the AT, and (b) consult with the student and his/her family and teachers regarding the potential for these experiences prior to implementing the AT (Day et al. 2001; Scherer 1998b). Also, to improve students' perception of AT as relevant to their personal goals for improved functioning, professionals can consult with the student and his/her family prior to implementing the AT.

Authors have published several instruments that formalize these preventative practices. The Assistive Technology Device Predisposition Assessment (Scherer 1998a; Scherer and Craddock 2002) structures the gathering of information on students' personal goals and, for a particular AT device, the potential for improved functioning, inconvenience, awkwardness, and social stigma. Tools for assessing students' satisfaction with AT after beginning implementation include the Quebec User Evaluation of Satifaction with Assistive Technology (Demers et al. 2002) and the Psychosocial Impact of Assistive Devices Scale (Day et al. 2002; Jutai et al. 2005). Additionally, useful information may be generated by the vision-specific quality of life measure Impact of Vision Impairment on Children (Cochrane et al. 2011).

Areas for Future Research

Areas for future research on AT and students with VI and blindness include (a) the reliability and validity of AT assessment methods' outcomes, (b) the efficacy of various AT in improving students' functioning, (c) students' preferences for particular AT supports, (d) the impact of provision of complimentary supports on visual functioning and related behavior (e.g., vision instruction, environmental modifications), (e) the effects of instruction on AT use, and (f) circumstances that influence the fidelity of AT interventions' implementation and the effectiveness of interventions. Given the paucity of research in these areas and the value of research findings to optimizing the education and development of students (IDEA 2004c), there is a great need for continued work in these areas.

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