Audio Assistive Technology and Accommodations for Students with Visual Impairments: Potentials and Problems for Delivering Curricula and Educational Assessments

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Abstract

Audio assistive technology and testing accommodations have become an increasingly prevalent and potentially useful means of promoting inclusivity in education. Technologies such as text-to-speech and other forms of audio information representation have helped to make curricula more accessible to people with visual impairments and other disabilities. Auditory accommodations in educational testing have also been implemented in an attempt to ensure equitable access to educational evaluations for people with disabilities. The potential benefits of audio assistive technology and accommodations notwithstanding, barriers remain to the implementation of audio in education for people with disabilities. Concerns with validity in audio tests, technical difficulties in the delivery of audio, and general stigma associated with the use of assistive technology and accommodations present formidable challenges that must be met before the full potential of audio assistive technology can be realized. This review examines current practices, potentials, and problems with the use of audio assistive technology and accommodations in educational settings.

Key words: text-to-speech, auditory graph, universal design, sonification, standardized testing
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The importance of advancing equality and participation in society for people with disabilities has been recognized by local (see, e.g., Thurlow, 2007), national (Australian Government, 2012; Dove, 2012; U.K. Department for Education, 2012), and international governing bodies (e.g., U.N. General Assembly, 2006). The widespread availability of computers and other devices with high fidelity audio capabilities has opened a multitude of possibilities for improving the delivery of curricula and ensuring fairness in educational assessment for people with visual impairments and other disabilities. Audio has become increasingly pervasive in many computing technologies (Edworthy, 1998; Flowers, 2005; Hereford & Winn, 1994; Kramer et al., 1999), though sound was examined as an information display as early as the 1950s (Frysinger, 2005). One important factor motivating the implementation of auditory displays in systems has been the desire to use assistive technology (AT) to meet the needs of populations of people with disabilities—especially people with visual impairments. When educational experiences become accessible with sound, collateral benefits may accrue for sighted learners. Further, sound may be an important tool for universal design (Nees & Walker, 2009)—an inclusive design approach that emphasizes accessibility for all people, including those with disabilities (Connell et al., 1997). The use of sound for presenting educational materials may also accommodate disparate learning styles or simply make learning more fun. As such, audio has begun to make curricula accessible for learners for whom traditional textbooks and visual materials are inadequate. Further, audio has played an important role toward ensuring people with disabilities are given fair opportunities to express their educational achievements and aptitudes in both classroom and high-stakes testing scenarios.

A recent study (Marder, 2006) suggested that the majority of students with visual impairments (especially those without comorbid developmental disabilities) are educated in general classrooms with their sighted peers and often participate in mainstream activities--including group work, writing assignments, and exams--with their classmates. Not surprisingly, most of these students accessed the educational curriculum with the help of some form of AT. Technology seems to afford access with some degree of success; Marder reported that almost half of the students with visual impairments and no concurrent developmental disabilities earned grades of “mostly As and Bs” in their classes. Human aids that read written information aloud to the learner (i.e., *oral readers)* were not commonly reported for students with low vision—a degree of intact visual capabilities. Only about a quarter of students who were blind used a human reader to access educational materials. Instead, nearly one-third of students who had low vision and about two-thirds of students who were blind reported accessing the educational curriculum with AT that used auditory presentation, including audiobooks and computer software.

Research (e.g., Sloutsky & Napolitano, 2003) has suggested that audition may be dominant over vision in young children in some circumstances; thus, audio may present unique learning opportunities for children (Droumeva, Antle, & Wakkary, 2007). The potential benefits of audio AT in educational settings extend across the entire age spectrum to students in higher education and even informal lifelong learning activities. Despite the tremendous potential for audio AT to promote participation and collaboration in educational settings with diverse learners, many outstanding issues remain with respect to the best practice use of audio AT. In this review, we weigh the potential benefits and difficulties of audio AT in educational settings. Our discussion is divided into three major sections: 1) audio AT for delivering educational curricula;

2) audio accommodations in educational testing; and 3) problems with audio AT and accommodations. Although our review is most immediately informed by policies and practices in the United States, the majority of the information presented has relevance in the United Kingdom (U.K. Department for Education, 2012), the European Union (Arsenjeva, 2009), Australia (Australian Government, 2012), and even in the Global South (Davison et al., 2012; Walker, Bruce, Nees, & Mwaniki, 2011).

Audio AT for Delivering Educational Curricula

Educational materials can be delivered in a host of presentation formats, including traditional textbooks and, increasingly, electronic books (e-books). Content may vary widely across courses and disciplines, but the fundamental components of most learning materials are weighted heavily toward text—words on the page or screen. Learning materials often also include figures, graphs, and diagrams in addition to text. Still other learning activities are experiential and involve hand-on activities or observations of exhibits. Our discussion of audio AT for delivering educational curricula has been organized around these components of educational materials and experiences, and we believe our review should generalize widely across many subjects and disciplines of study that use text, diagrams and graphs, and/or experiential activities to teach their respective curricula.

Audio AT for Text

Perhaps the most common audio AT is synthetic speech (Massof, 2003). Reading and written communication are prevalent learning activities, and the verbalization of orthographic information offers a flexible and adaptable means of non-visual communication. Synthetic speech is most often delivered via text-to-speech (TTS) engines, whereby the digital text from e-books, web pages, word processing software, e-mails, etc., is translated to an audible, speech-like signal. TTS sounds are different from natural human speech in that they are produced via computer algorithms, which introduce the potential for TTS to sound robotic and to produce idiosyncratic or errant utterances for some text. A wealth of research has examined the viability of synthetic speech as compared to pre-recorded natural human speech. In general, studies have shown that synthetic speech is more difficult to understand than natural speech, though practice does improve synthetic speech comprehension (Delogu, Conte, & Sementina, 1998; Reynolds, Isaacs-Duvall, & Haddox, 2002). The potential downsides of synthetic speech are balanced by the increased efficiency gained by allowing the user control over the rate of presentation with TTS, and a study suggested that time-compressed artificial speech may be easier to perceive and preferred over natural fast-talking (Janse, 2004). Research (Asakawa, Takagi, Ino, & Ifukube, 2003) has shown that practiced TTS users find presentation rates of up to 500 words per minute to be intelligible for some types of material. Even inexperienced users were able to recall content at TTS rates presented around one-and-a-half times faster than default system settings. From a design perspective, TTS is desirable over pre-recorded audio files of actual human speech, because the full catalog of potential utterances need not be anticipated and recorded a priori. Further, TTS algorithms have continued and will continue to improve; some current algorithms are almost indistinguishable from natural speech (Schröder, 2009).

TTS has been implemented with considerable success in screen readers—software packages that interface with a computer or mobile operating system to translate text, menus, and commands in the interface into audio. Screen reader users provide input using the computer keyboard, so the use of screen readers is heavily dependent upon keyboard shortcut keys (Kurniawan, Sutcliffe, & Blenkhorn, 2003). For example, pressing the “tab” key prompts the software to read aloud the text of available buttons in a dialog box (e.g., ”cancel” or “continue”), and pressing the “enter” key would select the active button (for a detailed account of screen reader functions, see Asakawa & Leporini, 2009). One estimate suggested that up to 3.5% of internet users access content via a screen reader, and difficulties with estimating the true prevalence of usage could mean that this is an underestimate (Practical eCommerce Staff, 2010). A recent survey suggested that almost all screen reader users have a disability, and the majority feel proficient with the technology and use it with desktop, laptop, and mobile computing devices (WebAIM, 2012). The survey also suggested that most respondents were audio-only users (i.e., they didn’t use the screen reader in conjunction with Braille or modified visual output).

TTS has also been implemented widely in increasingly popular e-books delivered via e-reader platforms. One of the potential advantages of electronic texts is their ability to provide flexible modes of output (including audio) and supplemental learning information to the reader (Anderson-Inman & Horney, 2007). Further, a recent survey (Bryant, Seok, Ok, & Pedrotty Bryant, 2012) suggested that audio books were the single most-used learning technology for people with intellectual and developmental disabilities. Even most of a general sample of college students who used e-books or e-readers found at least some value in the audio functions of such devices (Foasberg, 2011). E-books and related technologies open abundant opportunities for making educational materials accessible (Cavanaugh, 2002), and increasingly, applications developed for common devices such as smartphones and tablet computers also have usefulness as AT (Douglas, Wojcik, & Thompson, 2012).

When software applications and web content are designed to be accessible to screen readers (see, e.g., Asakawa & Leporini, 2009; Mankoff, Fait, & Tran, 2005), people with visual impairment or other disabilities can access the text content of a wealth of educational materials via audio. E-Books, web pages, and educational software can be studied in collaboration by students with and without visual impairments. Previous modes of alternative presentation such as braille were limited in availability, but digital educational materials are arguably more accessible to people with disabilities now than at any other time in human history (for a review, see Grammenos, Savidis, Georgalis, Bourdenas, & Stephanidis, 2009). Research also has shown that screen readers and TTS audio can benefit students with learning disabilities (see Anderson-Inman & Horney, 2007; Izzo, Yurick, & McArrell, 2009).

Although the direct translation of written language to speech may make the contents of many disciplines (e.g., language arts, social sciences) accessible, students in science, technology, engineering, and math (STEM) courses often encounter special cases of text (e.g., equations) that do not translate as readily to spoken audio (for a review, see Pontelli, Karshmer, & Gupta, 2009). In response, systems for translating equations and other mathematical and scientific notation to audio for use in conjunction with screen readers have been prototyped (e.g., AudioMath, see Ferreira & Freitas, 2004; also see Karshmer, Pontelli, & Gupta, 1999). The best practice use of audio presentation for equations and scientific notation is still being researched, but these systems might incorporate some combination of TTS and also tones or other nonspeech auditory cues—broadly dubbed *sonifications*. Though a detailed review of sonification is beyond the scope of this article, several detailed reviews are available (e.g., Kramer et al., 1999; Walker & Nees, 2011).

Auditory Displays for Graphs, Tables, and Diagrams

Beyond text and equations, non-text graphics are ubiquitous in learning materials (e.g., Peden & Hausmann, 2000; Zacks, Levy, Tversky, & Schiano, 2002), especially in science (Smith, Best, Stubbs, Archibald, & Roberson-Nay, 2002). The translation of graphics to the auditory modality is less straightforward than text. In general, accessibility guidelines dictate that web images should be manually "tagged" by web developers with hidden verbal descriptions that are activated by screen readers (Petrie, Harrison, & Dev, 2005; W3C, 2008). Some attempts have been made to automatically produce textual descriptions of graphs from data (Moskovitch & Walker, 2010) that could then be delivered via TTS. The benefits of visual graphs, however, lie in their ability to communicate information (e.g., trends) about the underlying data or function practically instantaneously with visual markers. The gestalt "pop-out" perception of trends and other patterns in graphs are the primary benefit of graphical representation (for a review, see Nees & Walker, 2007), but verbal descriptions of graphs lack these beneficial qualities. Audio versions of common types of graphs (especially coordinate line graphs), however, have been developed, and these auditory graphs seem to function comparably to visual graphs for graphing tasks common to learning activities (Bonebright, Nees, Connerley, & McCain, 2001; Davison, 2012; Flowers, Buhman, & Turnage, 1997; Nees, 2012).

Auditory graphs typically represent the Cartesian y-axis in a visual graph with pitch, and the position of a note or tone as the graph plays in time indicates its position on the x-axis. The general approach of using pitch to represent quantity has been used to create auditory versions of visual data representations, including box plots (Flowers et al., 1997; Peres & Lane, 2003), scatterplots (Bonebright et al., 2001; Flowers et al., 1997), and histograms (Flowers & Hauer, 1992). Empirical studies of auditory graphs have shown that they adequately convey information about central tendency and the shape of distributions (Flowers et al., 1997; Flowers & Hauer, 1992, 1993). Linear trend information is readily perceived in an auditory graph, although the extraction of local trend information becomes more difficult for the listener as the number of trend changes in the data increases (Nees & Walker, 2008). Hetzler and Tardiff

(2007) reported considerable success using auditory graphs to teach calculus, and Davison (2012) has begun integrating auditory graphs into primary school classrooms for students with visual impairments. The interested reader is referred to Nees and Walker (2007) for a detailed review of the literature on auditory graphs and Brown and colleagues (Brown, Brewster, Ramloll, Burton, & Riedel, 2003) for guidelines on auditory graph design.

In addition to graphs, tables and spreadsheets are common formats of data representation, and a number of researchers have examined ways to depict tables and spreadsheets with audio. Hetzler and Tardiff (2006) built an add-on tool for Microsoft Excel that sonified data functions in the spreadsheet cells. Ramloll, Brewster, Yu, and Riedel (2001) compared speech display of tabular data to a system that used both speech and nonspeech sounds (that mapped quantities to pitch). The hybrid speech and nonspeech system lowered perceived workload and decreased the amount of time participants needed to complete data analysis tasks in the study. In general, the use of nonspeech sound (pitch in particular) seems to be helpful for understanding the data in spreadsheets, especially as the data set becomes larger. With many data points, speech output alone makes exploration of tabular data time-consuming and imposes considerable memory demands, and it appears that at least some of these difficulties are alleviated with sonification rather than speech presentations of quantitative data. Well-designed sonifications within spreadsheets have shown promise for aiding data exploration and making data more accessible. Brown et al. (2003) provided design guidelines for using sound to present tabular data.

Audio in Experiential Learning

Though text, graphics, and tables are perhaps the most common materials for learning in traditional classrooms, audio AT has been developed for broader curricular activities such as games, fitness, and experiential learning activities (e.g., field trips). These “edutainment” or “learn through play” activities can supplement and enhance educational activities (Rapeepisarn, Wong, Fung, & Depickere, 2006), but people with disabilities may be shut out from these learning experiences without the development of AT that promotes inclusivity and participation.

Audio adaptations of children’s games (Targett & Fernstrom, 2003; Winberg & Hellstrom, 2001), arcade games (McCrindle & Symons, 2000), and adventure games (Liljedahl, Papworth, & Lindberg, 2007) have appeared and may facilitate inclusive play opportunities in educational settings. Audio AT may also play a role in facilitating play that encourages physical fitness. Stockman, Rajgor, Metatla, & Harrar (2007), for example, designed an audio soccer game, and beep baseball (for a discussion, see Massof, 2003) is a popular sport that uses a ball and bases with simple, embedded auditory cues for athletes who are blind. Audio has been introduced to facilitate rowing (Schaffert, Barrass, & Effenberg, 2009) and speed skating (Godbout & Boyd, 2010). A recent exploratory study (Barrass, Schaffert, & Barrass, 2010) began to examine the potential for sonification to be deployed flexibly across a wide array of exercise activities, including jogging, dancing, yoga, walking, swimming, and martial arts.

Experiential learning from exhibits and museums can also contribute to educational development. A system for using audio to convey dynamic movement of fish in an aquarium, for example, was recently discussed (Walker, Kim, & Pendse, 2007), whereby movements of fish are tracked by cameras with computer vision algorithms and the resulting data drive a sonic composition. Similar audio approaches could be used to make museums and other educational exhibits more accessible (see Landau, Wiener, Naghshineh, & Giusti, 2005).

Audio AT in Educational Testing

Audio AT for meeting curricular challenges may also be applied to testing students with disabilities in educational settings. The delivery of curricula and the assessment of the achievement of educational goals with tests are inter-related educational activities. For both learning and testing, equity for students with and without disabilities is the ideal. Students with some disabilities cannot take tests that were designed for the general population, but legislation increasingly has required that formal student assessments in schools include students with disabilities (for a discussion, see Zebehazy, Hartmann, & Durando, 2006). Formal policy aside, a study showed that teachers overwhelmingly felt that students with disabilities should be included in educational assessments, partially to ensure that teachers expend adequate effort toward educating students with disabilities (Weston, 2002). Students with disabilities, then, often take tests with accommodations—alternate testing formats or conditions that are intended to allow the test-taker to demonstrate her academic abilities or achievements independent from her disability. If a test cannot be administered via traditional visual modes, then the auditory modality presents the next plausible alternative. Oral readers are one of the most prevalent accommodations allowed in testing, and research has shown mixed results regarding both the efficacy of readers for improving scores and the impacts of readers on fairness in testing (Thurlow, 2007). Testing with oral readers and audio AT presents arguably all of the same challenges described for delivering curricula with sound, and a number of additional complications apply.

Difficulties with Validity of Audio Tests

The purpose of the test is a paramount consideration; achievement tests and aptitude tests are designed to accomplish different goals. Achievement tests generally test the extent to which particular knowledge or skills have been attained. In education, most classroom, subject-specific tests are achievement tests. Achievement tests, then, are concerned with “specific information,” whereas aptitude tests attempt to measure “the psychological operations fundamental to learning” (Tobin, 1984). Aptitude tests are generally intended to predict some future outcome (as opposed to measuring the current level of performance), such as when an admissions test is used to predict a prospective student's future grades. Under-prediction occurs if a test inaccurately suggests that a student with a disability will not succeed, whereas over-prediction means the test inaccurately predicts that a student with a disability will succeed (e.g., in college or law school) (for a discussion, see Geisinger, 1994). Advocates of fairness in testing have been primarily concerned with under-prediction, because under-predicting tests exclude deserving applicants from opportunities. Over-prediction is also problematic, however, because it potentially places unqualified students in the unfortunate position of being highly likely to fail, often at great expense, time, and emotional cost.

Whether the purpose of a test is to determine aptitude or to assess achievement, a number of criteria should be considered when assessing the impact of accommodations on equality and fairness in testing. Standardization is generally a desirable quality in testing scenarios. When a test is standardized, consistent rules for test administration and scoring are followed to ensure the same testing experience for every examinee. The time allotted for an examinee to finish a particular portion of the test and the test instructions are examples of aspects of tests that are often standardized, or held constant, across examinees (Geisinger, 1994). Mass-administered, standardized tests have become a familiar and somewhat notorious aspect of educational experiences, but even less formal quizzes and exams in classroom are usually roughly standardized such that all students are tested under the same conditions. The notion of standardized testing for people who are blind and visually impaired has, to date, been a contradictory concept. An accommodation, by definition, is an allowance for the test-taker to be examined under one or more exceptions to the standardized procedure. The need for individualized accommodations for fair testing of people who are visually impaired and other persons with disabilities presents considerable challenges for maintaining any standardized procedures whatsoever, as accommodations entail a large range of possible deviations from standardized procedures (Pitoniak & Royer, 2001).

Whereas standardization is often desirable, reliability and validity are mandatory prerequisites that must be established for any test to be meaningful. Reliability refers to the extent to which a test is consistent. A reliable test yields similar scores across repeated administrations and different versions of the same test. If a test is not reliable, then its results are meaningless and analogous to a measuring tape that returns different values for the same measured distance. To the extent that testing approaches for people who are visually impaired deviate from standardized procedures, reliability may decrease. Geisinger (1994), for example, points out that the reader of a test presented orally may influence the examinee's results to the extent that each reader does a better or worse job of reading the test aloud to the examinee. Reliability of the test is negatively impacted when two students of equal achievement or aptitude receive the accommodation of a test reader, and one student outperforms the other due to the characteristics of the different readers. One can imagine as many different sources of potential threats to reliability as one can imagine accommodations for test administration. Reliability is a gatekeeper for validity and must be established before a test can be valid.

Validity refers to the extent to which a test actually measures the achievement or ability that it claims to assess. Educational tests intended for the general population (e.g., pencil-and-paper tests) are clearly invalid for many test-takers with disabilities. The mere presence of an accommodation does not ensure validity, however, as the introduction of an accommodation can threaten validity to the extent that the accommodation changes the underlying construct (educational achievement or aptitude) that is measured by the test (Phillips, 1994). A valid accommodation allows a test-taker with a disability a fair and equal opportunity to be measured on the educational achievement or aptitude being tested without hindrance from the disability as a function of the testing materials or situation (see, e.g., Phillips, 1994). The accommodation improves test scores that would otherwise be lower due to a mismatch between the testing conditions and those aspects of the test-taker's disability that are irrelevant to the test material (dubbed "construct irrelevant variance", see, e.g., Weston, 2002). Further, a good accommodation *only* makes up for the test taker's disability without providing any additional advantage. If a particular accommodation would benefit *all* test takers, then the accommodation has exceeded its purpose and potentially becomes unfair by giving the person with a disability an advantage that is not available to unaccommodated test-takers.

As an example to illustrate validity issues, a test-taker who was blind would likely score near floor (i.e., chance performance) if given a traditional pencil-and-paper math test, because the person cannot see the test. As such, the pencil-and-paper test is not a valid measure of the person's math ability. The fact that the person cannot see is irrelevant to assessing the person's mastery of math—the purported intention of the test. A reader might allow the test-taker who was blind to exhibit her mastery of math. Further, the reader would likely not offer much benefit for test-takers without disabilities who could already read the words on the page. As such, this accommodation would meet the criteria for a valid accommodation by selectively allowing the person with a disability to reveal her academic achievement without providing a general advantage to all test-takers. In fact, evidence has suggested that oral readers offer a viable accommodation for students with reading or learning disabilities on achievement tests for math (Bolt & Thurlow, 2007; Sireci, Scarpati, & Li, 2005; Tindal & Ketterlin-Geller, 2004). Weston (2002) presented evidence to show that an oral accommodation improved the scores of students with disabilities—especially students with poor reading skills. The accommodation showed further selective effects in that it had a larger impact for questions with words (as opposed, for example, to questions with numbers). Further, for the most part the oral accommodation brought test scores more in line with teachers' ratings of the students' academic abilities.

Despite research that has shown positive results with oral readers as a testing accommodation (especially with math tests), a number of concerns remain with this approach (for an overview, see Pitoniak & Royer, 2001). Tests that were designed to be administered orally to all test-takers, such as the verbal portion of some intelligence tests, show reasonable validity for examinees with visual impairment without any accommodations (Reid, 1997) , but the fundamental construct being measured may change when a test that was designed to be taken under pencil-and-paper administration is simply read aloud. The equivalence of visual and auditory presentation of verbal information often has been assumed, but this assumption may be questionable. Auditory presentation, for example, may place considerably higher demands on test-takers to remember large amounts of auditory information, whereas the test-taker in pencil-and-paper administrations can simply refer back to her paper exam as needed (for a review of these issues, see Nees, 2012). A colloquial belief persists that people with visual impairment will perform better on tests involving listening. There is some evidence to suggest that people who are blind perform better than sighted people on average on Digit Span tests that use auditory presentation (Vander Kolk, 1977), and this effect is probably due to practice with auditory memory. Other research, however, has suggested that the advantage is only present in congenitally blind populations (Hull & Mason, 1995), and there is little evidence to suggest that this small advantage on a particular type of auditory memory test will transfer to other types of tests that were originally validated under conditions of visual administration. Simple auditory translations by an oral reader, then, may make visual tests invalid by changing the nature of the underlying ability or achievement being measured.

A related problem involves the equitable availability of adaptive test-taking strategies to test-takers with disabilities (for a discussion, see Nees, Berry, & Phillips, 2013). The Law School Admissions Council in the U.S. was recently sued by test-taker with a visual impairment (Rosenbaum, 2011; for an extensive review of legal issues surrounding testing accommodations, see Pitoniak & Royer, 2001). The test-taker's marks on the Law School Admissions Test (LSAT) precluded him from admission to law school, though his educational background and accomplishments suggested that he was otherwise qualified. The suit questioned the validity of the analytic logic games section of the test under oral administration. Under visual administration of the test, examinees are explicitly encouraged to use diagrams to help them to solve the problems. This strategy was not available to the test-taker who was blind, and the administrators of standardized, high-stakes test have shown some reluctance to allow test-takers with disabilities to use AT (e.g., screen readers, see Mattinson, 2012) during testing. As such, the unaccommodated test-taker is actively encouraged to use a strategy (diagramming) that is unavailable to the person with visual impairment, and the test-taker with visual impairment is denied the use of potential equalizers (via AT) that might be compensatory. In law school and eventually law practice, the person with a disability would presumably access legal materials with AT, thus the test may be underpredicting the test-taker's aptitude to succeed by disallowing the use of AT that could otherwise be used to make up for the person's inability to use diagrams and other visual materials.

Another difficulty is that oral testing may hinder students by slowing their progression through test questions (Weston, 2002). A recent experimental study suggested that audio versions of tests indeed required a slower pace through test questions. Nees (2012) showed that an all-audio (TTS and auditory graphs), computer-based approach to both learning *and* testing was equally as effective as an all visual approach for naïve students studying basic statistics concepts, though students who had either learned or were being tested with audio required considerably longer (sometimes up to twice as much time) to complete the test. This effect was not entirely attributable to the speed of the TTS delivery of questions and answers; instead, the auditory format per se seemed to require additional processing time.

The administration of verbal auditory tests has not been standardized to account for differences in the speed of readers' delivery of questions and other cognitive differences with hearing versus seeing a test. It is not surprising, then, that listening to questions and answers takes longer than reading the same material from text. Auditory administrations of tests are frequently given in conjunction with other accommodations, especially extended test-taking time (Elliott, Kratochwill, & McKevitt, 2001). The introduction of extended time, however, adds another layer of complexity to debates regarding fairness in accommodations. Extended time in some cases has been shown to benefit the scores of all test-takers. Studies of the LSAT, for example, suggested that extra time compromised the validity of the test by overpredicting grades, whereas all other accommodations that did not involve extra time appeared to be valid (Amodeo, Marcus, Thornton, & Pashley, 2009; Thornton, 2002). To further complicate matters, some research has shown that, although extra time benefits all test-takers, the magnitude of the benefit is greater for test-takers with disabilities. This raises the difficult question of whether the benefit of the accommodation for test-takers with disabilities outweighs the downside of not allowing all test-takers access to an accommodation that could increase everyone's scores.

Establishing the validity (or lack thereof) of any particular testing accommodation empirically remains difficult. In practice, the nature of the disability and the accommodation for testing are perpetually confounded, because accommodated versions of tests are only taken by people with disabilities. Thus, any observed deficit in scores on accommodated tests (e.g., on average compared to testing under standardized conditions) cannot necessarily be attributed to a faulty test. The test indeed may be unfairly underestimating the achievement or aptitude of the test-taker with a disability as a result of flawed testing formats or procedures, but another possibility is that some tests are accurately measuring lower achievement in students with visual impairment due to their impoverished exposure to learning materials. Of course there is no evidence that the general intellectual capabilites of people with visual impairments are different from the general population, but people who are blind may score lower on Arithmetic, Information, and Comprehension portions of intelligence tests, for example, perhaps due to a lack of exposure to the types of information on these tests (Vander Kolk, 1977). Research has suggested that children with visual impairment, for example, did worse than their sighted peers on comprehension items in intelligence tests that were loaded more heavily with content related to visual experiences (Wyver & Markham, 1999). These children did not perform worse than sighted children on comprehension items that were not dependent on visual experience . Some (Goldman, 1970; Vander Kolk, 1977) have suggested that the visual-perceptual metaphor of many verbal concepts results in only a surface understanding of these verbal concepts for people with visual impairment.

A dilemma exists, then, in that the experience with and exposure to the content of many achievement tests may be different for persons with visual impairments as compared to sighted persons, and this has lead for some researchers (e.g., Geisinger, 1994) to call for careful studies of the content of standardized tests. An achievement test is intended to assess mastery of specific learning materials or knowledge. A major concern with accommodated tests is the elimination of all construct-irrelevant variance from the testing scenario (Weston, 2002). In short, this means that scores on the test should not be affected by the presence or absence of a disability per se and should only reflect achievement of the specific knowledge being tested. Achievement testing demands a lenient approach to accommodation. The student with a disability should be given every opportunity to fairly demonstrate her mastery of the learning material with a valid test that does not penalize her test score as the result of a mismatch between the test format and the constraints of her disability.

These tensions with validity are different for aptitude tests, because the tests are designed with different purposes in mind. Aptitude tests are often intended to assess more general abilities that predict performance in a future academic or work-related context. Removing content from an aptitude test solely because it may disadvantage test-takers with disabilities could be problematic. Often the content in question (i.e., for which fairness in access or experience has not been determined) may actually be a useful content domain for predicting some outcome (e.g., success in college or at a job) for which the test has been validated. If a person has experienced lack of access to a particular visual content domain that prohibits adequate performance on an aptitude test, the lack of familiarity with that particular content domain may also predict poorer performance in future scenarios (school, jobs, etc.) where the content domain is relevant. This is not a flaw of the test—to the extent that the test has predictive value the test is simply fulfilling its design purpose. In some literature (e.g., Geisinger, 1994), the implication seems to be that standardized tests should be purged of content domains for which people with visual impairment have not had equal access or experience, regardless of whether or not these domains have predictive value for a future outcome.

A different, and likely better, approach is to improve the curriculum and delivery of these content domains to equalize access and experience long before a standardized test of achievement or aptitude for these domains is ever administered. Auditory graphs are but one example of how traditionally visual experiences have found cross-modal metaphors in audio, and AT may be able to further bridge the gap between audio and other visual experiences. The extent to which these sensory substitutes can stand in for actual visual experiences remains to be empirically determined with further research, but audio AT approaches have shown promise for conveying visual experiences with sound (see, e.g., Amedi et al., 2007). Accessible delivery of the curriculum is arguably a pre-requisite for fairness in testing. If students with disabilities experience relatively impoverished curricula due to inaccessibility of educational materials and learning opportunities, we cannot expect fairness to be reflected in scores on even the most accessible and equitable tests.

Problems with Audio AT and Accommodations

Beyond issues with the validity of auditory testing accommodations, lingering confusion remains about how to use sound to present information to people (Frauenberger, Stockman, & Bourguet, 2007). Difficulties specific to audio AT come in addition to the basic difficulties associated with all domains of AT. Holmes & Silvestri (2012) criticized the assumption that AT is effective for students with learning disabilities in higher education. The good intentions of providing AT notwithstanding, the authors argued that the empirical evidence supporting the efficacy of AT is flimsy.

Technical difficulties have persisted, even despite the advancement of technology. Upson (2001) reported practical difficulties in implementing audio in a math class that included software difficulties, problems with volume during presentation, and challenges with seamlessly integrating sound into existing, visually intensive graphical curricula. Connelly (2010) reported similar difficulties with using a combination of audio and tactile tools for teaching and testing a computer science student who was blind. Even with more widespread use of screen readers, a number of difficulties, including poorly designed webpages and software incompatibilities, continue to be reported by screen reader users. Users of screen readers, however, are resilient against technical difficulties (Lazar, Allen, Kleinman, & Malarkey, 2007) and develop strategies to circumvent technical shortcomings (e.g., Borodin, Bigham, Dausch, & Ramakrishnan, 2010). It is important to note, however, that technical difficulties with AT arise beyond routine problems associated with using computers and the internet. Basic computing skills for teachers students are a prerequisite for the implementation of AT, and this can present insurmountable challenges for users still grappling with overcoming the digital divide (see, e.g., Davison et al., 2012).

The basic properties of sound pose another technical difficulty. Whereas a visual display presents information in a specific location that is only available to people with a line of sight on the display, auditory displays are omnidirectional (Kramer, 1994) and obligatory (Sanderson, 2006). This property of audio may present benefits or challenges depending upon the context in which the auditory interface is implemented. When learners are working cooperatively and information needs to be shared, the omnidirectionality of sound may be an asset (Watson & Sanderson, 2004). Under other circumstances, though, the sound produced by an audio AT might travel to adjacent rooms and cause distraction, interference, or annoyance. More personal delivery methods such as headphones offer a possible workaround where the omnidirectional nature of sound is problematic.

A sociotechnical dilemma with AT is the match between the learner and the technology. Visual impairment manifests in diverse ways (Marder, 2006), so standardized approaches to fitting students with AT are unfeasible. A major challenge has been selecting AT to best meet an individual's needs (Bouck, 2010). Researchers have begun to develop tools for predicting the best match between users and AT (Scherer, Sax, Vanbiervliet, Cushman, & Scherer, 2005) and measuring the impact of AT (Jutai & Day, 2002). Unfortunately, the end users of AT, deferring to the recommendations of AT professionals, may be insufficiently involved in the selection of their own technologies and devices (Parette & Scherer, 2004).

Just as matching AT to a student's individual needs has proven difficult, fitting the right accommodation to a student to allow fairness in testing presents a considerable challenge. Policies vary widely across states (Cahalan-Laitusis, 2004), and a study found that elementary and middle school teachers were not adequately knowledgeable about the permissible accommodations for students with disabilities on state-mandated standardized achievement tests (Hollenbeck, Tindal, & Almond, 1998). In another study, teachers could not accurately determine which of their students would perform better with a read-aloud accommodation (Helwig & Tindal, 2003). The stated preferences of students for print (for low vision), oral, or braille administration of tests did not necessarily match the medium with which they performed best (Erin, Hong, Schoch, & Kuo, 2006). Students in one study reported a preference for a pencil-and-paper test administration even while reporting that they felt their test scores would be better under oral accommodations (Weston, 2002). When probed for further explanation, the students cited the duration of accommodated tests and their relative lack of independence during testing as factors driving their preferences . Another study found that the use or non-use of existing AT by students with blindness or low vision did not offer much value in predicting performance on standardized tests (Freeland, Emerson, Curtis, & Fogarty, 2010). In summary, research has shown that currently: 1) teachers are not able to determine the right accommodations for students; 2) students are not able to determine the right accommodations for themselves; and 3) use of AT does not impact test scores, probably in part due to mismatches between the technology and the individual or the testing scenario.

A critical social difficulty is the stigma attached to the use of AT in classroom situations where peers might perceive the student with a disability to be different or a member of an outgroup. Stigma can impair the effective implementation of AT if teachers are intimidated by technology and unable to help AT users to assimilate effectively in the classroom (see, e.g., Parette & Scherer, 2004). Upson (2001), for example, encountered some skepticism and lack of interest from educators in his efforts to incorporate audio into math classes. Stigma can be perpetuated when teachers and peers carry the perception that AT may be offering students with disabilities an unfair advantage (Bouck, 2010). Shinohara and Wobbrock (2011) reported notable misunderstandings of AT, including both 1) the notion that AT eliminates disability; and 2) the impression that people with disabilities that use AT are over-reliant upon the technology or accommodation. Legitimate concern exists over the potential for abuse of accommodations by students without disabilities, but these may coexist with counterproductive stigmatizing attitudes. Research has suggested that students who are outperformed by peers with disabilities who were tested with accommodations view those peers with considerable acrimony (Egan & Giuliano, 2009). Thus, the stigma associated with use of AT in the classroom seems to extend to accommodated testing scenarios, and negative feelings toward classmates with disabilities may be even more intense in competitive testing situations.

Shinohara and Wobbrock (2011) suggested that building accessibility into mainstream devices could eliminate some social stigma associated with AT use. In one poignant example, a participant reported purchasing an assistive device with “the ugliest earbuds…like bright orange or something…they just thought…since it was a bunch of blind people…it didn’t matter” (pp. 708-709). Users of AT share the same concerns as the general population with regard to aesthetics and social acceptability of personal technology, and Shinohara (2012) has begun to advocate for the deliberate consideration of social acceptability in AT design.

To date, however, the primary driver of AT implementation has been legislative policy aimed to ensure equality of access to education (Konur, 2006). Unfortunately, the enforcement of these policies (at least in the U.S) often has been accomplished through time-consuming and costly litigation (see, e.g., United States Department of Justice Civil Rights Division, n.d.). In many instances, companies, organizations, and institutions establish their own criteria for reasonable access and accommodations. While progress undoubtedly has been made toward enabling equality in education since the introduction of these policies, best practice examples with audio AT remain difficult to find.

Conclusions

Given the lack of viable alternatives to visual educational materials and tests, audio will inevitably play an increasingly important role in AT and accommodated testing. The arrival of digital technologies has made sound a mode of information presentation in most computing devices, and this development has somewhat inadvertently opened a wealth of new possibilities for audio AT in education (e.g., Cavanaugh, 2002). Devices that speak with TTS technology have made digital text in e-books, web pages, and software widely accessible to people with visual impairments and other disabilities. Graphs and diagrams present additional challenges for audio information representation that have begun to be met. Standards for the accessible design of internet materials have been developed by an international consortium (W3C, 2008) and continue to evolve.

A best practice approach to accessible testing also will include a substantial audio component for students with visual impairment and some learning disabilities. Read-aloud accommodations—especially those delivered with computer-based approaches (e.g., TTS) in lieu of a human reader—have shown potential for making tests accessible. To date, however, these accommodations often have been administered as ad hoc solutions for delivering tests that were validated for pencil-and-paper administration. A productive approach to providing fair accommodations may be to develop computer-based tests that provide alternate modes of access such as TTS and auditory graphs and diagrams. Screen readers or "self-voicing" systems have been implemented (Dolan, Hall, Banerjee, Chun, & Strangman, 2005; Hansen, Lee, & Forer, 2002) in lieu of human readers, and this approach may allow for more standardized, reliable, and efficient delivery of audio tests, which could possibly obviate the need for extended time with audio accommodations. Tests could then be validated in large-scale trials where all modes of presentation are available for all test-takers (i.e., a test-taker without a disability could still optionally access the audio used by people with a disability). This universal design approach has been advocated previously (Elbaum, 2007; Ketterlin-Geller, 2005; Salend, 2009) and may offer a path toward fair testing that also overcomes social stigma.

Increased teacher training may offer a potentail remedy to many AT barriers (Flanagan, Bouck, & Richardson, 2013). Available evidence has suggested that teachers generally view AT positively (Garcia & Seevers, 2005; Van Laarhoven, Munk, Lynch, Bosma, & Rouse, 2007). Yet a recent survey (Alkahtani, 2013) showed that teachers overwhelmingly felt poorly (or not at all) prepared to deliver AT, had little or no knowledge regarding AT, and rarely or never considered implementing AT. In fact, lack of training and support for both teachers and students is consistently cited as a major barrier to implementation (Alper & Raharinirina, 2006; Bouck, 2010; Flanagan et al., 2013). Flanagan and colleagues (2013) aptly pointed out the disconnect between extant research (like much of the material cited here) and current practice. Ultimately, better training and support may help to bridge the gap. The outstanding problems with audio AT seem to be highly solvable. Several critical areas for successful AT and accommodations implementation in education—including increasing technological capabilities, a growing base of empirical evidence, a willingness and desire to educate students with disabilities, and an active policy dialogue—have progressed steadily in recent decades.

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