Using Technology to Support STEM Reading

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Tasks in science, technology, engineering, and mathematics (STEM) are unusually varied because they target phenomena occurring in diverse domains and call upon a wide range of abilities to perform them. The fact that STEM tasks cover such a broad spectrum of abilities makes these fields uncharacteristically inclusive: Individuals with disabilities may perform well in STEM even if they face impairments in other academic domains. Despite this fact, people with executive function disorders face numerous challenges carrying out functions critically important for STEM, which often preclude the unique contributions that they could potentially make to these fields. For people with dyslexia, reading is an obvious challenge. In a typical college-level chemistry course, for example, students are assigned texts containing close to 1,000 pages, calling for the mastery of more than 300 specialized terms. Reading STEM content can be especially challenging because the text cannot be glossed over, but instead must be read closely, with attention to detail. Here, we describe how a technique we call Span-Limiting Tactile Reinforcement (SLTR) can help students with reading disabilities manage attention and working memory demands typically invoked in the close reading of text. SLTR facilitates close reading by reformatting the text into a single newsprint-like column with only a few words per line. The column of text is presented through a masking window in which the text is advanced manually as it is read. We implemented SLTR using STEM content on the Apple iPhone/iPod Touch and carried out experiments with eight college students with dyslexia and eight typical readers. Here, we present findings demonstrating the potential of this approach.

Science, technology, engineering, and mathematics place stringent demands on working memory and attention that pose special challenges for students with disabilities pursuing studies in these fields. Many of these tasks, such as reading, require focused attention and a systematic visual search. For example, finding an atomic weight on the periodic table of elements, computing a multi-digit product by longhand, or looking up a number in a table of binomial probabilities all require focused visual attention and working memory. When attending to information at the center of the visual field (e.g., solving a complicated multiplication problem by hand), mechanisms of attention act to shut out visual distractions by reducing perceptual sensitivity to information that lies away from the fixation point (Plainis, Murray, & Chauhan, 2001; Schwartz et al., 2005). As the problem is analyzed, the gaze jumps from one fixation point to another, once every ~250–500 ms, requiring information obtained in the center of the visual field to be suspended in working memory so that it can be used in the subsequent stages of the problem.

People with disabilities such as ADD/ADHD, dyslexia, or autism spectrum disorders typically face impairments in attention and working memory that can make such processes difficult (Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). Dyslexia, for example, is linked to visual attention deficits that make it difficult for individuals to ignore distracting information in the peripheral visual field (Bednarek et al., 2004). Students with dyslexia also find it difficult to process and hold visual or aural information such as a digit string or unfamiliar term in working memory (Vasic, Lohr, Steinbrink, Martin, & Wolf, 2007). Taken together, such impairments create challenges for these students when performing some STEM tasks.

While people with learning disabilities are perhaps the most susceptible to such challenges in STEM, they are not the only ones affected by executive function deficits. Students with disabilities of all sorts, whether blind, deaf, or physically challenged, often must contend with elevated cognitive loads associated with their disability. For example, they may need to deal with discomfort or pain, maintain balance, keep mental counts, or be aware of environmental cues—all of which can easily overload their capacity for working memory and attention. Therefore, even though a person who is, say, blind or wheelchair bound may not be diagnosed with attention or working memory deficits, this person may nevertheless experience similar symptoms due to the physical and environmental constraints he or she also must manage. Thus, the range of people dealing with heightened attention and working memory demands may be much broader than suggested by typical disability diagnoses.

Surprisingly, although executive function deficits can hinder a student's ability for STEM, these same deficits can be helpful in certain STEM contexts. This seeming contradiction can be understood simply as follows: Abilities for attention allow a person to inhibit peripheral distractions, thereby facilitating focused tasks, such as reading, that occupy the center of the visual field. However, these same abilities act to diminish peripheral sensitivity, which is a key capacity in certain global visual tasks, such as the ability to learn the general layout of a graph or image. Therefore, a person with typical abilities for attention may be less sensitive to global environmental features outside the central visual field when compared with a person who is disabled. As if on a seesaw, abilities for focused attention counterbalance disabilities for holistic perception, and vice versa (Schneps, Rose, & Fischer, 2007).

In the broad learning contexts of STEM, a person with an executive function deficit often can display potentially useful strengths resulting from the disability. The attention deficits associated with ADD/ADHD and dyslexia, which lead to visual distractibility, often are counterbalanced by strengths for peripheral sensitivity (Facoetti & Molteni, 2001; Geiger et al., 2008; Geiger & Lettvin, 1987). These capacities for peripheral sensitivity can be advantageous in some contexts important to STEM. Dyslexia is not the only disability associated with advantages for STEM, however. The hyper-focused attention associated with autism spectrum disorders is at the opposite extreme from the focusing disability associated with ADD/ADHD and dyslexia. Yet, it can facilitate visual search and enhance abilities to note detail (Barnes et al., 2008; Plaisted, O'Riordan, & Baron-Cohen, 1998; Remington, Swettenham, Campbell, & Coleman, 2009; Smith & Milne, 2009). Perhaps as a consequence, people with tendencies for autism were observed to be overrepresented in STEM (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001).

In general, a number of authors have argued that several of the giants in the history of physics, such as Bohr, Maxwell, and Einstein, were among those with cognitive disabilities, suggesting that the revolutionary insights these individuals have brought to their work in STEM may be attributable to unusual ways of thinking associated with their disabilities (Shaywitz & Shaywitz, 2005; West, 1999; Witelson, Kigar, & Harvey, 1999). Whether or not these historical figures had learning disabilities is a matter of debate, but there is no question that numerous contemporary leaders in STEM fields—such as Baruj Benacerraf, who won the Nobel Prize in Medicine in 1980, and Carol Greider, who won the Nobel Prize in Medicine in 2009–perform at exceptional levels in STEM fields despite learning disabilities (Fink, 2006; Nuzzo, 2005).

Using Technology to Circumvent Barriers that Inhibit STEM Learning

The foregoing discussion raises a serious challenge for STEM fields. STEM has the capacity to be broadly inclusive in its scope by valuing the unique contributions of individuals typically underrepresented in these fields. As previously described, these individuals may excel in certain tasks associated with these fields. However, the academic rigor of professional pathways to STEM often acts as a major barrier for them. How can these fields support individuals with executive function disabilities who, despite typically poor performance in school, bring special aptitudes that are important to research? While the answer to this question is multifaceted and complex, we suggest that technology might be one way to partially ameliorate these concerns.

Computer technologies can provide mechanisms to help focus attention and buffer working memory, thereby minimizing demands placed on these executive resources in various applications. Among the tools currently in use for this purpose are screen blockers used to reduce distracting visual content and FM microphone systems to help students minimize auditory distractions in spoken lectures (Purdy, Smart, Baily, & Sharma, 2009). Computers can assist working memory by providing search capabilities, such as those offered by Google Desktop or Apple Spotlight, that allow students to search content on their computers using cut and paste techniques. These search tools also allow approximate keywords (rather than exact matches) that rapidly retrieve details that would otherwise place high demands on working memory abilities. In addition to attention and working memory supports, assistive technology helps people with executive function deficits manage the demands of reading, spelling, and organizing writing. These tools are now a part of all standard commercial word processing programs such as Microsoft Word or Apple Pages, including advanced text-to-speech and speech-to-text capabilities (e.g., Nuance Dragon or MacSpeech Dictate).

For people with dyslexia especially, reading is an obvious challenge. In a typical college-level chemistry course, for example, students are assigned texts containing close to 1,000 pages, calling for a mastery of more than 300 specialized terms. Reading STEM content can be especially challenging because the text cannot be glossed over; it necessitates reading closely, word-for-word. This need for close reading, and for narrowly specific mastery of vocabulary, distinguishes reading required for STEM from reading in many other contexts. Although many interventions have been proposed to support people with reading disabilities, few have considered special requirements pertaining to STEM (for a review of interventions, see Lovett et al., 2000).

Attention Training

Attention is observed to respond to training (Tamm et al., 2008), and methodologies for attention training (ATT) have been proposed to help students manage task demands that call for control over the allocation of attention. A number of authors, including Sinotte and Coelho (2007) and Lorusso, Facoetti, Paganoni, Pezzani, and Molteni (2006), have explored the possibility that ATT could help children improve their reading ability, which has prompted research investigating applications of ATT for dyslexia. Geiger and Lettvin (1987) conducted one such early experiment investigating the efficacy of ATT for reading. They used high-speed tachistoscopic techniques to briefly (~10 ms) flash a pair of letters simultaneously at the center of fixation and in the periphery. Participants were asked to identify the letter pairs, and the accuracy of their response was recorded. The researchers found that the participants' ability to accurately name the letter pairs rapidly declined as the separation between the letters was increased. For typical readers, the ability to accurately name the letter pairs diminished to chance levels when the span was greater than 8°. However, this perceptual span was observed to be greater in people with dyslexia; participants with dyslexia were able to name the letter pairs accurately on average 5° further to the periphery compared to those who were typical readers. One participant in particular, a 25-year-old man with severe dyslexia, was especially sensitive to the peripheral stimuli. He was able to name the letter pairs 20° into the periphery, almost a factor of three further into the periphery than typical readers. Such findings suggest that dyslexia may be associated with enhanced peripheral sensitivity that in turn may lead to distractibility and visual confusion during reading.

Geiger and Lettvin (1987) devised an intervention regimen for the person with severe dyslexia that included reading practice using a paper attention mask, together with eye-hand coordination tasks such as painting and drawing. Eye-hand training was considered important in their regimen because of evidence suggesting that visual strategies are learned through the development of spatial information gained from other senses (Held & Bauer, 1967). The reading practice involved the use of a visual attention mask made by cutting a window in an ordinary sheet of paper. The window admitted only eight or nine letters of text when placed over a printed page. A mark was made about 35mm to the left of the window, and the participant was asked to fixate on this mark as he scanned the window over text to read. This fixation mark was positioned so that the participant read using the portion of his visual field, slightly toward the periphery, measured to be most sensitive in tachistoscopic tests. After three weeks of unsupervised practice, the man with severe dyslexia was able to measurably reduce the width of his peripheral span, so that it was now comparable to those observed in other participants with dyslexia. Furthermore, this individual, who previously read at a third grade level, was now able to read at levels closer to the tenth grade.

Encouraged by Geiger and Lettvin's initial demonstration as well as an extensive series of follow-up studies supporting their initial findings (e.g., Geiger & Lettvin, 1987; Lorusso et al., 2004), Lorusso, Facoetti, Paganoni, Pezzani, and Molteni (2006) carried out subsequent studies, including those using a computerized intervention incorporating ATT called FlashWord (Masutto & Fabbro, 1995). This computerized intervention trained children with dyslexia to attend to words in the left or right peripheral visual field, according to each child's profile defining his or her individual subtype within dyslexia, as measured by classification schemes based on those developed by Bakker (1990). FlashWord combines ATT with hemisphere-specific word training by flashing words for 100–250 ms in the left or right peripheral visual field. After four months of treatment, Lorusso et al. (2006) reported significant improvements in reading accuracy, memory, and phonemic skills in children who received the hemisphere-specific tachistoscopic ATT treatment, compared with more traditional reading-focused training regimens typically used in Italy for the treatment of dyslexia (which focused mainly on training of phonological and perceptual skills).

Computerized Interventions to Support Reading

While visual training interventions incorporating attention training appear to be promising, such programs are as yet years away from wholesale implementation in schools. Among the programs currently in use, effectiveness varies widely from individual to individual and from program to program. Therefore, just because an individual is enrolled in such a program, there is no guarantee that the child will achieve reading mastery at the level required to learn challenging STEM content. Furthermore, not all children who stand to benefit from such interventions avail themselves of these programs. Many individuals with identified reading challenges decline interventions for various reasons such as stigma, while others may experience difficulties in reading but are nevertheless unidentified and untreated. Consequently, while training programs may be helpful for many children, they alone are not sufficient, and computer-based tools designed to help children cope with reading can be helpful for many. Among these are accessibility tools designed for people with low vision, such as text-to-speech conversion engines that are built into many commonly available word processors and text readers. Other computer-based interventions include integrated environments for reading and writing. These are intended to support people with learning disabilities. Examples include systems produced by Kurzweil and Read & Write.

Another way in which computers can help support those who struggle to read is to alter the formatting of text to ameliorate issues with oculomotor control. People with executive function deficits frequently have difficulty maintaining fixation and exhibit abnormal patterns of oculomotor control that make it difficult to direct their gaze and remain on task while reading (Eden, Stein, Wood, & Wood, 1994). People with dyslexia sometimes mention that text seems to jump around, perhaps a subjective statement of the difficulties they experience with oculomotor control. Difficulties with fixation exacerbate problems with working memory, disrupting the ability to keep ideas online as text is read and parsed (Loe, Feldman, Yasui, & Luna, 2009). Furthermore, those who have difficulties with working memory and attention are easily distracted by imagery or text on the page, or by sounds and other extraneous stimuli that further interfere with processes required for close reading in STEM.

One computer-based intervention that addresses issues with oculomotor control is Rapid Serial Visual Word Presentation (RSVP). RSVP flashes words one at a time in quick succession at a fixed location on the screen, obviating the need to guide the gaze along a line of text. RSVP has been used in experimental contexts to present text in event-related potential (ERP) studies of children with dyslexia, and it also has been considered a possible solution to screen size limitations posed by devices such as cell phones or PDAs (Paul, Bott, Wienbruch, & Elbert, 2006; Rahman & Muter, 1999; Russell & Chaparro, 2002). While RSVP still requires the ability to hold fixation, it minimizes the need to accurately track the gaze along a line of text by presenting words serially at a fixed location on the screen. However, a known drawback of RSVP is that it places very high demands on working memory. The lexical content of words, serially flashed at a fixed rate, must be held in working memory in order to parse entire sentences (Nieuwenstein & Potter, 2006). Furthermore, RSVP is susceptible to lapses in attention, since distractions that disrupt focus on the word stream will impede understanding. Thus, while RSVP addresses issues of oculomotor control, it also places high demands on working memory and attention, which may be particularly problematic for the readers we hope to support.

Span-Limiting Tactile Reinforcement (*SLTR*) *in STEM Reading*

Schneps, Rose, and Fischer (2007) point out that because people with cognitive disabilities can (under the right circumstances) outperform people otherwise considered unimpaired, the generally held definition of disability may need to be reconsidered. In particular, these authors define a parameter they call Periphery-to-Center Ratio (PCR) that groups individuals according to their relative abilities to make use of information in the peripheral visual field versus the central field. People with dyslexia are characterized as high PCR, as they tend to use visual strategies biased toward the periphery (Geiger & Lettvin, 1987). While interventions to support people with disabilities typically are designed to offset weaknesses, the perspective proposed by Schneps et al. (2007) advocates an alternate model for intervention that builds on the strengths of individuals with disabilities. Here, we suggest it may be helpful to distinguish explicitly between two nonexclusive types of intervention and support:

Type I. Interventions designed to ameliorate a deficit; to counteract a specific challenge or need.

Type II. Interventions that enhance a talent; that build on unique assets offered by those who are disabled.

Supporting the distinction being made here between Type I and Type II supports, Baum, Cooper, and Neu (2001) and Mann (2006) point to the need to strike a balance in creating interventions intended for gifted/learning disabled students who exhibit strengths in areas such as spatial learning. These authors call for programs of intervention that both ameliorate deficits and enhance talents, a mix of what we describe as Type I and Type II supports, respectively (e.g., Burgstahler & Chang, 2009).

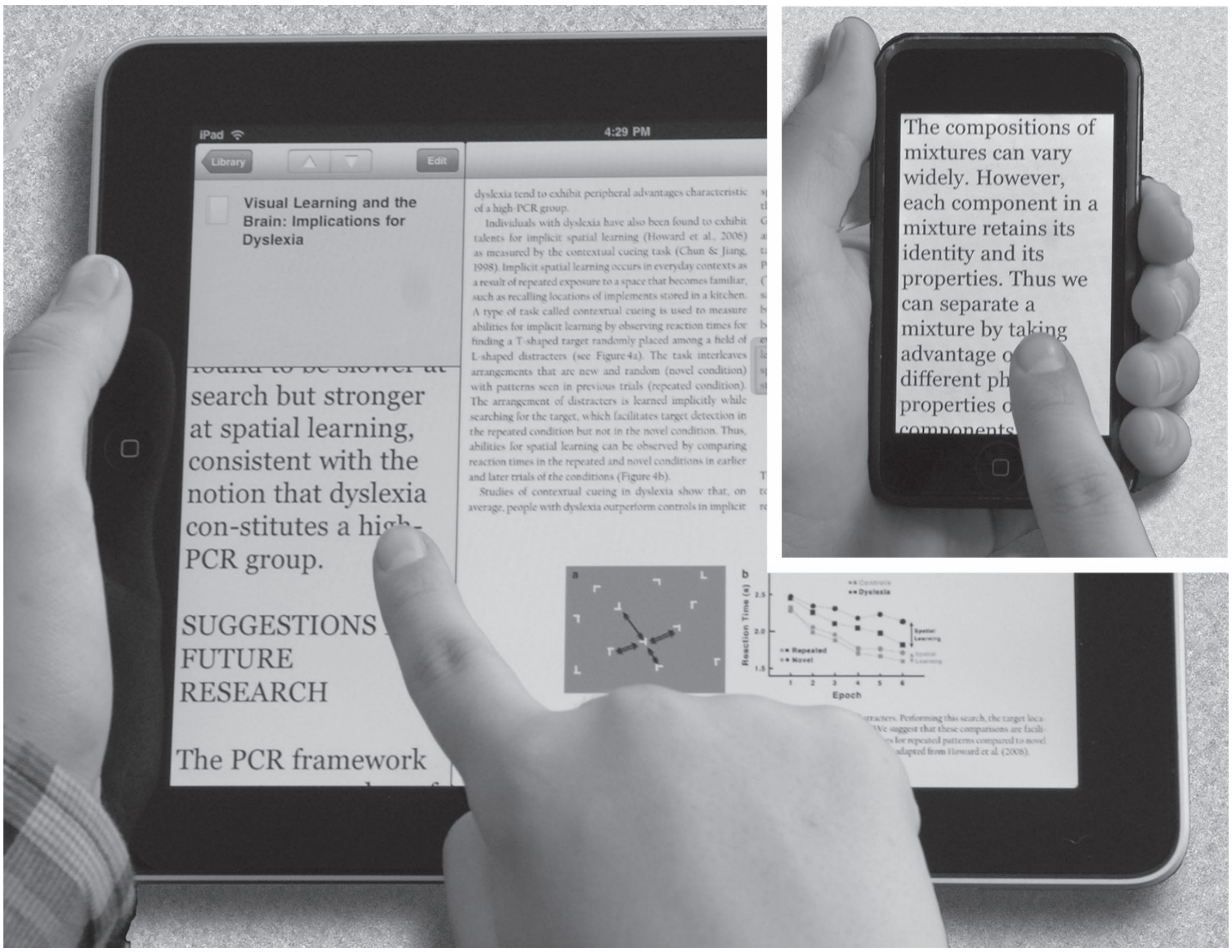
We additionally qualify our description by introducing the concept of strong Type II interventions: interventions that build on strengths resulting from the disability (that individuals who are unimpaired may lack). For example, a Type II intervention may help students who use a wheelchair build on their experience to better understand the physics of inclined planes. We would distinguish this from a strong Type II intervention that might help people with dyslexia become better aware, and take advantage, of visual strategies associated with their high-PCR capabilities for peripheral vision. The reading intervention proposed by Geiger and Lettvin (1987) that uses a fixation offset to encourage people with dyslexia to read using the peripheral portions of their visual field would be considered an example of a strong Type II intervention. It helps individuals with dyslexia capitalize on a strength resulting from their disability that typical readers often lack.

Span-Limiting Tactile Reinforcement (SLTR) is an alternative to the RSVP method that incorporates a strong Type II intervention. In SLTR, text is reformatted to form a single column, similar to a column of newsprint, that is approximately three words across. A viewing window with a width that equals the width of the column admits a few lines of text and blocks the rest (see Figure 1, upper right). Readers are encouraged to keep their gaze at the top of the viewing window, reading the uppermost line and then advancing the column of text as they go. They advance the text with a finger, which provides tactile reinforcement that helps punctuate their progress through a paragraph of text.

SLTR builds on the RSVP approach to reduce peripheral distractibility by limiting the amount of text presented at any given time. However, while the serial presentation of text in RSVP increases demands on working memory and attention (by demanding a steady focus on a forced flow of text), SLTR addresses this drawback by allowing readers to control the pace at which information is assimilated. Furthermore, while RSVP presents words one at a time, SLTR displays a group of about three words per line (and a portion of surrounding text), to allow readers with dyslexia to capitalize on the associated high-PCR bias. This strong Type II component of the intervention builds on advantages for peripheral processing linked to dyslexia. Lastly, SLTR incorporates tactile reinforcement to provide additional sensory input believed to aid in comprehension (e.g., Campbell, Helf, & Cooke, 2008).

Figure 1

SLTR (as implemented on an Apple® iPod Touch in our study, inset) and a mock up of a proposed implementation of SLTR on an Apple® iPad.



In summary, SLTR incorporates the following design principles:

1. **Present text in a span-limiting window**. Presenting text in a window that is only three words across limits the attention load required to parse the text, and at the same time relaxes demands on abilities for fixation. In providing grouping of about three words per line, readers with dyslexia are able to quickly parse a segment of a sentence, taking advantage of abilities for peripheral processing associated with their disability. The narrow window further acts to reduce distractibility and also functions to direct the reader's gaze, to ameliorate difficulties with eye movement control.
2. **Allow manual advance of text**. Text is read by manually advancing the column of text within the viewing window. In this way, readers can control the rate at which text is advanced in order to match their capacities for working memory and attention. Furthermore, demands on oculomotor control are greatly reduced as readers manually advance text with a finger (rather than scanning down the text with the eyes). Lastly, the manual advance function reduces attentional demands by helping readers keep their place as they read. The line of text at the top of the window moves

on only when the column is manually advanced, thereby minimizing distractions that might otherwise dislocate the fixation point, as well as serving as a marker that prevents readers from losing their place.

3. **Use kinesthetic reinforcement**. Students are encouraged to read by leaving their gaze fixed near the top of the window and advancing the text one line at a time via a jockey wheel (or some other device). This finger action provides tactile-kinesthetic reinforcement that punctuates each short phrase while reading. This tactile-kinesthetic reinforcement is thought to promote comprehension—similar to approaches incorporated in reading interventions designed for people with dyslexia, such as Orton-Gillingham and Wilson Reading (Campbell et al., 2008; Joshi, Dahlgren, & Boulware-Gooden, 2002).

When taken together, we expect these design principles to be especially beneficial to readers with executive function deficits. Specifically, we hypothesize that students with dyslexia will demonstrate greater gains in STEM content knowledge when using SLTR, as opposed to conventional reading on paper. While SLTR may be beneficial for all readers, we speculate that these gains will be more pronounced among students with dyslexia.

A pilot experiment was undertaken to determine the efficacy of the SLTR implementation by examining results in college students with dyslexia as well as college students with no known reading impairments. The pilot implementation of the SLTR design built on capabilities of the Apple iPod Touch. Here, the reflow feature in the Adobe PDF standard was used to strip passages of STEM text of their formatting. The text was then redisplayed as a single newsprint-like column that could be manually scrolled up and down using the device.

Method

Participants

Eight undergraduates diagnosed with dyslexia (from Landmark College, a preparatory college for students with learning disabilities) and eight undergraduates with no prior history of learning disabilities (from Harvard University and the University of Massachusetts, Boston) participated in the pilot study.

Materials

A multiple-choice test was used to probe chemistry content knowledge before and after students read passages from the textbook, *Chemistry: The Central Science* (Brown & LeMay, Jr., 1988). Students read this text using both SLTR and traditional paper methods. To preclude a possible learning effect through repetition, a different text passage was read using each technique. Text A consisted of 443 words, approximately 70 of which were STEM-specific terms. Text B consisted of 429 words, approximately 45 of which were STEM-specific terms. (The average readability level for this material was 8.9 on a Flesch-Kincaid Reading Age scale.)

Gains in content knowledge were measured in a pre-/posttest design. Before reading the chemistry textbook passage, each participant was given a 14-item paper-and-pencil test (on which the maximum score was 14 and the lowest was zero). These test items were adapted directly from exercises provided in the textbook, accompanying the specific text passages read by the students. An example of a test question follows (the correct choice is the final one in the list).

Which best describes a liquid (choose the best answer):

- ☐ It does not have a fixed volume or shape.
- ☐ It can be compressed to fit a small container.
- ☐ It takes the volume and shape of its container.
- ☐ It has a definite volume but no specific shape.

After reading portions of the text, students were retested using a similar instrument. The postreading questions additionally contained an item comparing their qualitative experience with paper vs. SLTR reading, along with four other self-assessment questions about their overall academic experience. For example:

Choose one:

- ☐ I strongly prefer reading on the iPod.
- ☐ I prefer reading on the iPod.
- ☐ I prefer reading on paper.
- ☐ I strongly prefer reading on paper.

Procedure

Text for the pilot was uploaded from the textbook to an Apple iPod Touch, and a commercially available iPhone/iPod application, called GoodReader (Selukoff, 2009), was used to display the text (see Figure 1, upper right). A reflow setting in the GoodReader application was used to reformat the text so that it was presented in a narrow window, using Georgia 32-point font that displayed approximately three words per line. The text was black against a green-yellow background.

The pilot experiment compared reading via SLTR on the iPod to reading on paper. Both tasks began with a brief training session involving reading a block of practice text presented in the particular method format. The practice text was the same for each method; the text consisted of three paragraphs comprising 233 words, describing general advice for studying chemistry. For the iPod task, the training session additionally included an initial 70-word tutorial on the SLTR method. For both tasks, readers were allowed to read the tutorial and practice text at their own pace, and were encouraged to ask questions about the particular method before proceeding with the task. The time taken for each practice session was typically less than 10 minutes.

The previously described multiple-choice test was used to probe participants' baseline chemistry knowledge before reading. After the pretest, participants read corresponding content (Text A or Text B) taken from the textbook and then took the test again (posttest). Each student read Text A followed by Text B, and each student used both iPod and paper. The design was balanced in regard to the sequence of reading methods to take potential sequence effects, such as learning or boredom, into account. Among the participants with disabilities and those in the control group, a randomly selected half of the group did the iPod reading first (on Text A) and then the traditional reading (on Text B), whereas the other half did the opposite. The task was not timed; readers were allowed to read at their own pace. Typically, an entire session, including the signing of consent forms and training in the reading method, ran approximately one hour per participant.

Analysis

We used a mixed method design. In the quantitative part of analyzing the test-retest performance under the two different reading methods, repeated measures ANOVA was used, which was implemented through PROC MIXED in the 9.2 release of the SAS statistical package (SAS Institute, 2008). The target alpha level was 0.05 (two-tailed). The independent variables of interest were the between-subjects variable group (dyslexia vs. control), the within-subjects variable method (iPod vs. traditional), as well as their interaction. Two control variables were text (Text A vs. Text B, which also identifies testing order) and method sequence (iPod first vs. iPod second). The sequence variable played no role and was dropped. Students scored higher, on average, on Text A than on Text B. This was particularly noteworthy for the students in the control group who, on the pretest, averaged 13.1 (out of 14) points, so that there was a potential ceiling effect on their gains on Text A. (This was less of a problem for the other combinations: control group Text B pretest mean = 9.4; dyslexia group Text A pretest mean = 11.1; dyslexia group Text B pretest mean = 6.5.) Consequently, the gain for Text B was larger by 1.1, which was marginally significant ($p = 0.07$). In addition to this quantitative analysis, we also asked the participants to respond to qualitative questions about their reading experience with each method.

Results

The outcome variable was the gain in content knowledge, as measured by the difference in pre- and posttest scores. The grand mean of the gains after reading was 1.3, indicating that the participants, on average, answered 1.3 more questions correctly after reading. The standard deviation of the gains was 2.2.

The main effects model showed that the gain did not differ between the dyslexia and control samples. As expected, the main effect for reading by iPod was positive (0.9). In terms of effect size, this would be a substantial gain, corresponding to 41% of the standard deviation of the dependent variable, but did not quite reach significance in this small study ($p = 0.10$). The interaction model showed no significant interaction effect between method (iPod vs. traditional) and group (dyslexia vs. control). However, whereas the advantage of iPod reading over traditional reading in terms of gains was relatively smaller for the dyslexia group (1.8 vs. 1.1), the iPod method had a surprisingly larger advantage for the control group (1.9 vs. 0.6).

Discussion

Reading on an iPod using SLTR technology was observed to be superior to conventional reading on paper for those with dyslexia; however, the small scale of this study and the resulting lack of statistical power precluded significance. A greater (though also nonsignificant) advantage of iPod reading was observed in the typical readers than among those with learning disabilities. We attribute this to the possibility that the benefits of iPod reading in the dyslexia group were masked by rigid reading strategies and/or previous accommodations that these students had become accustomed to while reading on paper. The Landmark students took as much as five times longer to read on paper than did the control group, and they did so using a variety of strategies (e.g., following text with a finger while speaking the words aloud). Had our pilot experiment included measures of reading time, the advantage of iPod reading over traditional reading may well have been significant in the dyslexia group, even in this modest pilot study.

The fact that the iPod intervention produced any gains in the dyslexia group seems especially remarkable when one considers that the students with dyslexia received extensive training in the strategies that they used for reading on paper but less than an hour of training using SLTR. In contrast, the control group students, who were skilled at reading on paper and who did not use any accommodative techniques, showed even larger gains using the SLTR technique. This suggests that the SLTR technique may be highly effective in supporting close reading among students who face challenges in reading yet have not received any formal training in reading strategies. SLTR provides built-in supports (e.g., span-limiting viewing window) that function in similar ways to the reading strategies observed in the dyslexia group (e.g., following text with a finger). Therefore, a struggling reader who has not yet developed successful reading strategies may find SLTR to be more beneficial than a struggling reader who has developed elaborate, paper-based reading strategies. Whereas this small pilot study could not establish that the participants with dyslexia did better when reading on the iPod than when reading on paper at the conventional statistical significance level, it produced strong evidence that they did not do worse. The fact that the students with dyslexia experienced no significant loss in comprehension using the SLTR technique—despite having only minutes of training in SLTR and years of training in paper-based strategies—points to the tremendous promise of this technique.

While talented readers often view reading as pleasurable and enjoyable, people with dyslexia sometimes report feelings of trepidation when faced with the prospects of reading large blocks of text. This automatic negative emotional response exacerbates their challenges in reading. Given that SLTR greatly limits the amount of text displayed, we thought that it might also serve to reduce the negative effects associated with reading. In response to our qualitative questions about the students' reading experience with each method, most students with dyslexia (four out of five who responded) found the iPod preferable, while the reverse (one out of five) was true for those without dyslexia. Thus, while the typical readers did not see an advantage to the SLTR technique, the readers with dyslexia found the experience beneficial. One student with dyslexia wrote, "it was less donting [daunting] reading in small amonuts and was easyer not to get over wellmede [overwhelmed]."

Postulated Advantages of SLTR

We speculate that one reason the SLTR technique may be especially effective for those with dyslexia is that the method is better matched to their peripheral span, which, as observed by Geiger and Lettvin (1987), is typically greater in dyslexia. While various processes ordinarily conspire to limit the span of reading in typical readers, for any number of reasons this span may be effectively larger in people with dyslexia. This larger reading span leads to visual confusion and difficulty parsing words presented in a sentence. We suggest that SLTR may help by (a) reducing confusion from words to the right of the fixation point, and (b) offering a limited multiword segment of text that can be parsed using their broader perceptual span without a need to shift their gaze. In effect, the SLTR technique allows readers with dyslexia to use their broader peripheral span to "gulp in" chunks of text, three words at a time, and process each chunk before manually advancing to the next line.

Another reason SLTR may be advantageous is that it serves to minimize reading errors associated with the production of regressive saccades and backtracking associated with dyslexia (Biscaldi, Gezeck, & Stuhr, 1998; Rayner, 1998). When using SLTR, readers fix their gaze near the top of the viewing window, and then manually advance the text by hand—as opposed to visually scanning along a row of text. This physical act of sliding the text upward with a finger may, in itself, act as tactile-kinesthetic reinforcement that punctuates the sentence fragment being processed. In addition, the SLTR technique allows readers to move the text while the eyes remain stationary, rather than the other way around. Accordingly, this reading technique may ameliorate the effects of any impairment in abilities for eye movement control, such as those associated with dyslexia (Eden et al., 1994).

Lastly, given that the text only moves when manually advanced, this technique is expected to be relatively insensitive to distractions that cause readers to lose their place. If distracted, readers can simply return their gaze to the top of the window to continue where they left off. The viewing window acts as a finger that consistently points to the place in the text. Thus, the SLTR approach greatly reduces the demand for attention, which is believed to be impaired in people with dyslexia (Facoetti et al., 2010).

Proposed Future Implementations of SLTR

A serious drawback of the current implementation of SLTR on the Apple iPhone/iPod Touch is that, because the window provides a restricted view of the text, the technique cannot be used to skim easily through a paper to build an overview of the content. The Harvard University Bureau of Study Counsel (HUBSC) offers a long-standing course designed for Harvard undergraduates, first taught in the 1940s and updated continuously ever since, that promotes techniques for effective reading and study practice. The reading course teaches, among other approaches, strategies that incorporate active thinking about the intent of the author revealed through the structure of the document. Students are taught to skim works for headings, key phrases, figure captions, and other clues that elucidate overall structure and meaning of the text. Students also are encouraged to make written notes of key ideas, paraphrased in their own words. HUBSC finds that these techniques allow students to read large volumes of text quickly with high rates of comprehension when compared to more time-consuming methods based on word-by-word reading. Unfortunately, our current implementation of SLTR is not commensurate with the overviewing techniques advocated by HUBSC.

An alternate implementation of SLTR might incorporate a dual window display presented either on a computer screen or on a tablet device such as the Apple iPad. A mockup of such a device is present in Figure 1 (see left side). Here, a large window displays a PDF image of the text that can be scrolled, zoomed, and scanned, as with any PDF reader, to allow for a rapid overview of structure and content. SLTR would be implemented in a smaller side window that displays the same content in a reflow format, as in the current implementation. The text displayed in the small SLTR window would be linked to the file in the larger window via a navigation marker (see Figure 1, left side). The navigation marker could be moved at will in the larger file to locate the SLTR window where needed. As in the current implementation, text in the SLTR window would be advanced using a finger swipe or a jockey wheel. The proposed hybrid approach allows readers to shift seamlessly between the two reading methods: exploring the broader layout of the document in the larger PDF window and carefully close reading difficult passages using the side window for SLTR.

Conclusions

The study of STEM can be challenging for students because it often requires careful close reading of difficult content, a process especially challenging for those with executive function deficits. We tested an implementation of the SLTR approach using commercially available software on the Apple iPhone/iPod Touch. We demonstrated that this technique can be mastered with only a few minutes of instruction and practice, and yet, even with limited exposure, it may be at least as effective for promoting comprehension among college students with dyslexia as other highly practiced compensatory methods. Furthermore, we found that, in students who are unimpaired, the SLTR approach is more effective for close reading STEM content than reading similar material on paper. We postulate that SLTR is effective because it reduces demands on working memory and attention, limits the need for oculomotor control, and uses tactile reinforcement to foster retention.

Although these results are encouraging, we emphasize that this is a small study. Further work is needed to test the effects of potential biases due to the novelty of this technique as well as to explore long-term considerations such as its effects on retention. Future experiments would use eye tracking to investigate the hypothesis that SLTR minimizes the need for eye movement control, which is currently postulated to be an important strength of this method. A future implementation also would test the feasibility of SLTR as an adjunct to screen-based PDF readers, which would allow students to benefit from the close reading support of SLTR as well as the overview and skimming techniques afforded by the PDF reader display. Screen-based implementations of hybrid SLTR systems could use a mouse with a jockey wheel to navigate through large volumes of text. An implementation on touch-based tablet devices such as the Apple iPad may be especially effective for this purpose. Furthermore, current implementations of commercially available eReaders for small screen devices (e.g., Apple iBooks, Barnes &Noble eReader, or Amazon Kindle for iPhone) could readily be modified to incorporate SLTR techniques to expand their utility for those who struggle to read and thus make eBooks more broadly accessible.

We conclude that the SLTR approach has shown promise as a highly effective technological application for supporting students who struggle to read in STEM. SLTR may be especially useful for those who struggle with reading but who have not yet developed effective compensatory reading strategies (whether due to a lack of formal training, a lack of formal diagnosis, or various other reasons). This research illustrates how technology can be used to support people with learning disabilities, especially in contexts that are important to STEM, where the content demands a challenging level of detail and comprehension. The demands for close reading in STEM can be overwhelming for students with learning disabilities. Therefore, technologies such as SLTR can help ensure that these students do not become discouraged by STEM reading demands so that they may participate at the highest levels in these exciting and challenging pursuits.

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