Do Multimedia Instructional Designs Enhance Comprehension in College Students with Dyslexia?

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Abstract

The current study tested the effects of multimedia instructional designs (text+picture, audio+picture, and text+audio+picture) on retention and transfer of information in college students with and without dyslexia while tracking students' eye movements. After controlling for verbal ability, the dyslexia group differed from controls only in the text+picture condition. Retention performance for the dyslexia group was optimal in the no written text (audio+picture) condition. Eye-tracking data showed that the dyslexia group spent significantly more time viewing the picture when audio augmented written text. These findings show that students with dyslexia can learn as easily from multimedia instruction as their peers and multimedia combinations can be manipulated to optimize specific learning outcomes.

Keywords: Dyslexia, multimedia instruction, eye-tracking, retention task, transfer task

Historically defined as the ability to communicate and learn through written modalities of language, literacy has evolved to encompass skills that go well beyond text reading and writing. Multimodality or multimedia learning environments are now commonplace in colleges and universities and technological advancement, such as e-learning and online platforms, requires that virtually all students engage in multimedia modes of instruction. However, it is currently unknown how students with dyslexia compare with their non-disabled peers in these multimedia instructional environments. Considering that the number of students with dyslexia entering postsecondary institutions has been steadily increasing in the last several decades (Government Accountability Office, 2009), understanding how multimedia instruction affects learning outcomes in students with dyslexia is an important endeavor.

Multimedia instruction is defined as the combined use of several media to promote learning (Mayer, 2009). The most common type of multimedia instructional design combines text with pictures. A commonly held belief is that pictures facilitate comprehension of concepts through text presentation. For students with dyslexia who have had a difficult time in text-dominant educational environments, the addition of visual modalities may significantly enhance their academic success. However, this remains an open question. The purpose of this study was to investigate whether students with dyslexia differ from their peers when learning science content from instructional designs that combine verbal and nonverbal representations of the same concept.

Effects of Multiple Representations on Learning Outcomes

A primary aim of dyslexia research has been to understand how affected individuals process phonological and orthographic representations, especially with regard to learning to read. The current study focuses instead on how individuals with dyslexia integrate multiple representations of the same concept in learning academic content. Using a classic multimedia learning experiment (Mayer, 1997), students were first presented with instructional lessons under varying multimedia conditions. Learning outcomes were then assessed through retention and transfer questions. Retention questions require simple recall of learned material whereas transfer questions require that recently learned material be applied in new ways or situations (Mayer, 1997).

Multimedia effects on learning were examined through Ainsworth's (2006) Design, Functions, Tasks (DeFT) framework.

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> [The DeFT framework] proposes that the effectiveness of multiple representations can best be understood by considering three fundamental aspects of learning: the design parameters that are unique to learning with multiple representations; the functions that multiple representations serve in supporting learning and the cognitive tasks that must be undertaken by a learner interacting with multiple representations." Within the DeFT framework, the present study explored how instructional designs (i.e., text+picture, audio+picture, text+audio+picture) can affect the pedagogical function (learning) across two different cognitive tasks (retention and transfer task).

Regarding the relationships between the design and function aspects of the DeFT model, research suggests that students learn better from multimedia lessons containing words and pictures than from lessons containing only words (e.g, Mayer, 1997; Moreno & Valdez, 2007; Schnotz & Bannert, 2003). This advantage, known as the *multimedia effect* (Mayer, 2009; Mayer, Heiser, & Lonn, 2001), has been documented in both book-based and computer-based learning environments (Mayer, 2003). For example, in a series of Mayer's studies (Mayer, 1989; Mayer & Gallini, 1990), students were randomly assigned to a word-only group or a words-and-pictures group and read on paper about how brakes work. The words-and-pictures group provided 79% more creative solutions on problem-solving questions than the word-only group. In a follow-up study (Mayer & Anderson, 1991), when presented with the same content (i.e., how breaks work) and questions on computer screen, students in the word-and picture group generated 97% more creative solutions than students in the word-only group. Mayer (2003) posits that multimedia presentation may result in deeper learning because the learner is encouraged to build both verbal and visual mental models as well as to build connections between the two models. However, research also suggests that the notion, "more is better," is not always correct. Kalyuga, Chandler, and Sweller (2004), for example, reported that students who received audio with diagrams outperformed students who received audio and text with diagrams. This finding is called the *redundancy effect* (Mayer, 2009). Mayer and Johnson (2008) explained that when learners have to spend their limited cognitive resources processing the redundant material, such as written and spoken text, they are less able to coordinate and integrate the necessary information needed for learning.

To study the task aspect of the DeFT model, researchers have analyzed student performance across closed-ended questions and open-ended questions. Close-ended questions are useful for obtaining specific pieces of information but, by their nature, they limit learners' responses and are influenced by the multiple choice options (Foddy, 1994). Conversely, open-ended questions do not limit learners' responses and elicit, instead, learners' generative processing during comprehension (Ozuru, Briner, Kurby, & McNamara, 2013). The types of open-ended questions can range from simple retention and recall of facts to more complex responses requiring problem solving and transfer of knowledge (Mayer, 1997). The addition of pictures may have different effects on different levels of learning. Mayer and Gallini (1990), for example, found that students performed better on transfer tasks when they read passages with illustrations about how scientific devices work than when they read passages without illustrations. However, no difference was found in the retention task. Consistent with the principles of the DeFT model, these findings suggest that retention and transfer tasks tap different levels of learning and that the advantage of including illustrations may vary according to cognitive demands of the specific learning outcome task. Accordingly, valid measurements of multimedia learning must include both retention and transfer tasks.

Effects of Multiple Representations on Learning for Students with Dyslexia

In addition to considering the effects of different representations or task requirements on learning (i.e., extrinsic variability), it is also as important to consider the learner's ability to process different types of representations (i.e., intrinsic variability) (Ainsworth & Lowe, 2012). For example, Adesope and Nesbit (2012) included reading level, education level, and prior domain knowledge as individual differences which affect learning with multiple representations. Reading level is a particularly important consideration in the present study because while adults with dyslexia often develop compensatory skills to overcome many of their reading deficits, learning difficulties remain (Simmons & Singleton, 2000). College students with dyslexia often fail to adapt to the academic demands of higher education (Kirby, Silvestri, Allingham, Parrila, & La Fave, 2008). Compared to typical peers, for example, college students with dyslexia experience more difficulty learning from lectures, complete fewer assignments (Fuller, Healey, Bradley, & Hall, 2004), and are more likely to withdraw from their course of study, especially during their first year (Richardson & Wydell, 2003). Thus, it is not surprising that college students with dyslexia also experience increased anxiety and low self-esteem (Nelson, Lindstrom, & Foels, 2015). To provide a learning environment in which these students can be successful, educators and student support service providers need to know how college students with dyslexia learn compared to their peers with typical reading skills (Pino & Mortari, 2014).

A few studies have experimentally tested the effects of multimedia instruction on learning in poor readers and the results from related studies have been mixed. For example, Beacham and Alty (2006) compared learning outcomes of young adults with and without dyslexia across three formats in which only the design was altered: sound and diagrams, text and diagrams, and text alone. Although students with dyslexia stated that they preferred the two designs that included diagrams, results from recall and transfer questions showed they performed best in the text alone condition. Rello, Saggion, Baeza-Yates, and Gaella (2012) explored whether the use of a graphic organizer could improve dyslexic students' text comprehension. They found that using graphic organizers improved students' reading speed but did not improve students' ability to answer closed-ended comprehension questions about the central ideas in the text. Taylor, Duffy, and Hughes (2007) presented animated data flow diagrams to college students with and without dyslexia and asked open-ended comprehension questions. Overall, the animated diagrams improved students' comprehension; however, students with dyslexia reported that the animated material was difficult to use. Additional empirical data is needed to determine whether multimedia instruction optimizes learning for students with dyslexia.

Present Study

Previous studies have focused primarily on understanding whether adding graphics (pictures, graphs, tables, etc.) to learning designs improves comprehension for students with dyslexia. Considering that recorded books are often prescribed for students with dyslexia (Esteves & Whitten, 2011), the present study focused on whether the addition of auditory input (i.e., recorded voiceover) as well as non-linguistic visual input would help or hinder learning in college students. Recall that the *multimedia effect* posits that multiple representations of a concept should facilitate learning, whereas the *redundancy effect* posits that the redundant multiple representations of a concept should hinder learning due to limited processing capacity. Thus, the goal of this present study was to test these effects in college students and to ultimately determine whether there is an optimal way to combine multiple representations of a concept to enhance retention and transfer of knowledge for college students with dyslexia. To do this, the instructional designs were experimentally manipulated to include various combinations of spoken language (audio recording of text), written language (text), and non-linguistic (picture) modalities. In addition, the study also explored whether varying the modalities of the instructional design would interact with different levels of learning across dyslexic and non-dyslexic groups. Several studies exploring multimedia effects in typical readers have included different question levels (Ginns, 2005 for review); however, it is unknown whether students with dyslexia would respond in the same way.

To provide further insight into the attention and cognitive processing load associated with integrating multiple representations of a concept, behavioral (comprehension questions) and physiological (eye movement) data were combined. The first objective was to compare comprehension on open-ended questions in response to three different multimedia designs (i.e., text and picture vs. audio and picture, vs. text, audio, and picture) and types of questions (i.e., retention and transfer questions). The second objective was to compare the two groups' eye fixation times for specific subregions on the presentation screen (picture and text) and eye movements between the subregions (picture and text) corresponding to the specific types of representations.

Methods

Participants

In total, 161 college students (55 students with dyslexia, 106 students with typical reading skills; mean age = 21.72 years old) participated in this study. Of the 55 students with dyslexia (DR), one was excluded from analyses due to technical problems with the eye-tracking equipment. Of the 106 students with typical reading skills (TR), three were excluded due to incomplete data collection and technical problems with the eye tracking equipment. The final cohorts of participants were composed of 54 college students with DR and 103 college students with TR. Students with DR were recruited through emails distributed by the university disability service office, announcements in undergraduate classes, and posters on campus. Students in the TR group were recruited through a university research participation website. All participants were native speakers of English and reported negative histories for pervasive cognitive deficits, behavioral disturbance, neurological illness, psychiatric illness, hearing impairment, or uncorrected visual impairment.

All potential participants were individually assessed to ensure that they met the inclusion criteria for this study. To be included in the DR group, students reported a history of reading difficulties beginning in childhood and scored at or below one standard deviation of the mean on word reading from the *Test of Word Reading Efficiency* ([TOWRE]; Torgesen, Wagner, & Rashotte, 1999). To be included in the TR group, students reported an absence of a history of reading difficulties at any time while in school. Their normal reading status was confirmed by their average or above average performance on the tests administered to the students in the DR group.

Verbal ability was assessed using the *Woodcock Johnson III Test of Cognitive Abilities* ([WJ-III-COG]; Woodcock, McGrew, & Mather, 2002) and visual sequential memory was assessed using the *Test of Memory and Learning*, second edition (Reynolds & Voress, 2007). Because the topic of the instructional lesson was lightning, a prior knowledge questionnaire developed by Moreno and Mayer (2002) was used to assess the students' background knowledge on meteorology. Students were asked to rate on a five-point scale (1 = very low, 5 = very high) their level of knowledge of meteorology and to place check marks next to each of seven weather-related items that applied to them (e.g., "I know what a low pressure system is" or "I can explain what makes the wind blow"). On the basis of F-tests with α at .05, the two groups did not differ on the mean age, education, visual sequential memory, or prior knowledge score; however, the students in the DR group had significantly lower reading and verbal scores (see Table 1). Low verbal ability in dyslexia has been frequently reported in previous literature (Ramus, Marshall, Rosen, & van der Lely, 2013; Rispens & Been, 2007; Robertson & Joanisse, 2010). Therefore, in the present study, comprehension and eye gaze data are reported after controlling for the verbal ability.

Finally, since students were randomly assigned to three experimental conditions (described in detail below), it was confirmed prior to subsequent analyses that there was no significant difference within DR groups across three conditions (text+picture, audio+picture, or text+audio+picture) for age, education, reading score, verbal ability, or prior knowledge (*ps* >.05). Similarly, there was no significant difference within TR groups across three conditions for age, education, reading score, verbal ability, or prior knowledge (*ps* >.05).

Materials

Instructional materials and comprehension questions used in the present experiment were adapted from Mayer and Johnson (2008). The experiment included a single lesson, comprising 11 PowerPoint slides which explained the formation of lightning. The slides advanced automatically. The total lesson lasted 88.02 seconds with an average viewing of 8.00 seconds per slide. The content was presented as either *text+picture, audio+picture,* or *text+audio+picture* (see Figure 1 for presentation examples). In the text+picture condition, the text described the steps in the formation of lightning and the pictures depicted the steps in the formation of lightning. Corresponding text and pictures were presented simultaneously. In the audio+picture condition, the slides included pictures with concurrent audio clips that contained the identical words in text. The audio clips were recorded by a female using Windows® Movie Maker 2001. In the text+audio+picture condition, text, audio clips, and pictures were included.

After watching the PowerPoint lesson, the students were asked five comprehension questions following the protocol developed by Moreno and Mayer (2002). Question types included one retention question and four transfer questions. The retention question was "Based on the lesson you just read/listen to, please describe how lightning is formed. Be as specific as possible." The four transfer questions were (a) what could you do to decrease the intensity of lightning? (b) suppose you see clouds in the sky, but not lightning, why not? (c) what does air temperature have to do with lightning? and (d) what causes lightning? In Mayer's original task, students read the questions and wrote down their answers; however, in the current study, given the reading difficulties of the students in the DR group, the experimenter read the questions to all students, recorded the answers the students verbally provided, and transcribed them after the experiment was completed.

Apparatus

Eye movements were tracked using an LC Technologies head-free EyeFollower binocular system operating at 120 Hz with a 0.45 degree gaze-point tracking accuracy throughout the operational head range. PowerPoint slides were presented on a 24 inch (61cm) light-emitting diode (LED) monitor with a resolution of 1920 × 1080 pixels. Fixations were extracted with a temporal threshold of 100 ms and a spatial dispersion threshold of 1.5˚(minimum deviation of 25 screen pixels). Participants sat at a distance of 23.62 inches (60 cm) from the LCD monitor and used a custom-designed keyboard for inputting manual responses. NYAN 2.0 software from Interactive Minds Eyetracking Solutions was used to analyze eye gaze data.

Procedure

Participants individually completed tasks in the following order: (1) general background and meteorology prior knowledge questionnaire, (2) reading and visual sequential memory assessment, and (3) experimental eye tracking task. Each participant was randomly assigned to a presentation group (text+picture, audio+picture, or text+audio+picture). The entire procedure took approximately one hour. Prior to the experimental task, the investigators explained the eye-tracking methodology and participants had time to become familiar with the equipment. This was followed by a nine-point calibration procedure. For the experimental trial, the researchers presented oral instructions, stating that the student would be presented an explanation of how the process of lightning works. When the presentation was finished, the investigators asked the five questions about the content. No time limit was given to answer the questions.

Statistical Analysis

First, to determine if the two reading groups differed in the retention and transfer test scores, univariate analyses of covariance (ANCOVAs) were conducted (n = 157). Group memberships (DR and TR groups) and presentation type (text+picture, audio+picture, text+audio+picture) were independent variables and WJ-III-COG verbal ability score was the covariate, and the retention score and the transfer score were the dependent variables. The verbal score was included to ensure that the results were not attributable to difference in language ability. The model was intercept + reading group effect + presentation type effect + interaction effect of reading group and presentation time + error. Bonferroni post hoc test was conducted to locate whether the differences occurred between presentation types in the main effects and the interaction effect. As an effect size measure, partial eta squared (η_p^2) was reported. The η_p^2, one of the most widely reported measures of effect size (Fritz, Morris, & Richler, 2012), is the proportion of variance that a variable explains that is not explained by other variables (Field, 2009). Effect size is defined small (0.01-0.06), medium (0.14-0.14), and large (> 0.14) (Acton, 2012).

Second, to determine if the two groups differed in the eye fixation times for two subregions (i.e., picture and text), a multivariate analysis of covariance (MANCOVA) was conducted (n = 107). Group membership and presentation types were the independent variables and WJ-III COG verbal ability score was the covariate, and the total gaze duration was the dependent variable. MANCOVA is the extension of ANOVA in which there are several dependent variables (Tabachnick & Fidell, 2013). Third, to compare eye movements between two subregions (picture and text), a univariate ANCOVA (n = 103) was conducted with the reading group and the presentation type as independent variables, WJ-III-COG verbal ability as a covariate, and eye movements between the two areas as a dependent variable. Data were analyzed using SPSS version 22.0 for Windows (IBM Corp, 2013).

Results

Group Comparisons of Comprehension Across Presentation Types

The first aim was to compare the two groups' response to the comprehension questions when information was presented in three different conditions (i.e., text+picture, audio+picture, text+audio+picture). Since the same five comprehension questions are used, the author of the original study, Mayer, provided an initial list of acceptable answers. After the first fifty participants completed the experiment, the first author and Mayer discussed additional possible answers based on their responses. A retention score was computed for each participant by counting the number of major idea units (score range: 0-14) that the participant produced. A transfer score was computed for each participant by counting the number of acceptable answers that the participant produced for four transfer questions (score range: 0-12). Interrater agreement in scoring was .93. For discrepancies, a third rater arbitrated and generated a consensus rating.

Data from 52 participants (18 DR and 34 TR) for the text+picture condition, 50 participants (15 DR and 35 TR) for the audio+picture condition, and 55 participants (21 DR and 34 TR) for the text+audio+picture condition were analyzed to compare response accuracy of students with and without dyslexia corresponding to the types of representations. ANCOVAs were conducted with group membership (DR and TR groups) and presentation types (text+picture, audio+picture, text+audio+picture) as the independent variables, response accuracy as the dependent variable, and WJ-III-COG verbal ability score as the covariate.

For the retention task, the reading group and presentation types significantly interacted after controlling for the verbal ability, $F(2, 150) = 6.91$, $p = .001$, $\eta_p^2 = .08$ (see Table 2 and bar graphs at top of Figure 2). The Bonferroni post hoc tests revealed that the DR group had significantly lower scores in the retention task than the TR group only for the text+picture condition, $t(150) = -4.15$, $p < .0001$. For the two other conditions, the audio+picture and the text+audio+picture conditions, the groups' retention score was not significantly different, *ps* > .05. Verbal ability, the covariate, was not significantly related to the retention score, $p > .05$. Additionally, while TR mean scores across the three presentation conditions did not differ (*ps* >.05), the DR mean score in the audio+picture condition was significantly higher than the DR mean score in text+picture condition, $t(150) = 2.95$, $p = .01$. The DR mean score in the text+audio+picture condition was higher than the DR mean score in the text+picture condition, but the difference did not reach the statistical significance ($p = .07$). For the transfer task, neither the group membership nor the presentation type significantly related to the transfer score, *ps* >.05 (see bar graphs at bottom of Figure 2). Verbal ability was not significantly related to the transfer score, $p > .05$.

Group Comparison of Eye Gaze Patterns across Presentation Types

The second aim was to compare the two groups' eye fixation times for specific subregions on the presentation screen (picture and text) and eye movements between the two subregions (picture and text) corresponding to the type of presentation. Only two conditions (text+picture and text+audio+picture) were used for the analysis because the current study focused on the two subareas (picture and text) and in the audio+picture condition, only pictures, but not text, were presented on the screen (see Figure 1 for scene example for audio+picture condition).

First, reading fixation times for two specific subregions (i.e., pictures and text) were compared across groups. A MANCOVA was conducted with group membership (DR and TR groups) and presentation types (text+picture, text+audio+picture) as the independent variables, total gaze duration on the picture and text areas as the dependent variable, and WJ-III-COG verbal ability score as the covariate. Total gaze duration was defined as the sum of the durations of fixations. The reading group and presentation type significantly interacted, $V = .07$, $F(2, 100) = 3.93$, $p = .02$, $\eta_p^2 = .70$. The following ANOVAs showed that the DR group spent significantly longer time on the picture area for the text+audio+picture condition compared to the text+picture condition, $t(100) = 2.44$, $p = .01$ (see Figure 3). On the text area, there was no difference between the reading groups or the presentation types, all *ps* > .05.

Second, eye movements between the two subregions (i.e., picture and text) were compared corresponding to the presentation type. The participants' eye movements for two conditions (text+picture and text+audio+picture) were manually coded. The scene viewed in the middle of the presentation (scene 5 out of 11 scenes) was selected and there were total 3,744 eye movements (427 eye movements between text and picture areas, 865 eye movements within picture area, and 2,452 eye movements within the text area). Data from four participants were excluded because more than 10% of their eye movements were not clearly presented. Thus, data from 50 participants (16 DR and 34 TR) for the text+picture condition and 53 participants (19 DR and 34 TR) for the text+audio+picture condition were used for the data analysis. The eye movement data were analyzed using 2 (reading group: DR, TR) × 2 (presentation type: text+picture and text+audio+picture) ANCOVA after controlling for WJ-III-COG verbal ability (see Figure 4). There was no interaction effect between the reading group and the presentation type, $p > .05$. However, the reading group was significantly related to the eye movements. The TR group showed more eye movements than the DR group, $F(1, 15.75) = 11.44$, $p = .004$, $\eta_p^2 = .42$.

Discussion

The first aim was to investigate the effects of multimedia instruction on learning in college students with and without dyslexia. The main finding was that groups performed similarly across conditions with one exception: when the instructional material was presented in a text+picture format, students with dyslexia scored significantly lower than their peers on the retention task, yet performance was similar across groups on the transfer task. This finding contributes to a broad literature base showing that after controlling for background knowledge, word reading deficits in dyslexia can impair comprehension (Lyon, Shaywitz, & Shaywitz, 2003). It also supports the notion that retention and transfer tasks tap different levels of learning and comprehension (Mayer & Chandler, 2001). However, the direction of performance in the dyslexia group was somewhat unexpected considering that the retention questions, which require only literal understanding, should be easier than the transfer questions which require inferencing and problem solving. It is speculated below as to why there is a significant group difference in the retention task but not in the transfer task.

One explanation is that students with dyslexia have developed good problem solving skills in order to compensate for poor word reading. Compensation skills or coping strategies of young adults with dyslexia have been frequently reported (Fink, 1998; Kirby et al., 2008). For example, Everatt, Steffert, and Smythe (1999) found young adults, but not children, with dyslexia were better at creative problem solving compared to non-dyslexic peers. They interpreted this developmental trend to suggest that inference or higher-level thinking skills develop over time as a coping mechanism. Other researchers, however, report that creative problem solving in dyslexia is related to inherent intelligence rather than to a developmental pressure for compensation (Ritchie, Luciano, Hansell, Wright, & Bates, 2013). Considering the discrepancy between groups on the retention task, perhaps a more plausible explanation for the main finding is not that students with dyslexia are especially skilled at problem solving but, rather, are impaired on tasks that require encoding, retention, or retrieval of very detailed linguistic information. That is, students with dyslexia in the present study may have been able to glean the gist of the lesson, but were unable to encode or recall enough specific details to adequately answer the retention questions. This could be directly due to the students' impaired reading ability or to other processing impairments common in dyslexia, such as poor working memory or poor verbal expression. Considering that the lesson was automatically paced, a third possibility is that students may have had inadequate time to read for detail and may have adopted a strategy of "skimming" rather than careful reading.

The second aim was to compare eye fixation and eye movements across groups in each of the multimedia conditions. Regarding eye fixations, the analysis showed significant group differences in the amount of time students allotted to viewing pictures. Specifically, students with dyslexia fixated longer on the picture area in the text+audio+picture presentation than in the text+picture condition. These findings suggest that in the text+audio+picture condition, students with dyslexia focused on the pictures while listening to the statements and this learning strategy helped them perform as well as the typical readers. However, in the text+picture condition, text and pictures competed for visual processing attention. Related to the eye movements, for both text+picture and text+audio+picture presentation, the typical readers made more eye movements between the text and the picture areas compared to the students with dyslexia. Thus, the typical readers were better able to integrate information from competing visual modalities (i.e., text and pictures) in both presentation conditions than students with dyslexia.

Implications for Theory

The current data show that students with dyslexia had better learning outcomes when the instructional design included spoken words with picture (audio and visual). This instructional design was more effective than the one that used only printed words and pictures (both visual). These findings are therefore consistent with the theory that learning is enhanced when instructional materials provide students with multiple representations that can be processed through more than one modality (Mayer, 2003). Therefore, the multimodality effect is demonstrated in the reading impaired population. In contrast, combining different types of multimedia instruction did not have a significant effect on learning in students with typical reading skills. Their performance in the audio+picture condition was similar to their performance in the text+picture condition. Mayer (2009) states that the multimodality effect is more apparent when the learning material is complex than when it is simple. It is possible that the learning material in this study may not have been complicated enough to overload typical readers' working memory capacity. In contrast, for the reading impaired students, even though the text consisted of simple vocabulary and sentence structures, replacing written text with the audio recording may have reduced the extraneous load of reading, which is the primary deficit in dyslexia.

The redundancy effect states that learning is hindered when information is repeated in different modalities (Moreno & Mayer, 2002). This detrimental effect occurs due to the divided attention to the unnecessary information so that cognitive resources become less available to process essential information. Eliminating redundant information has been showed to improve learning (Kalyuga et al., 2004). According to the redundancy effect, students' performance in the text+audio+picture condition should be lower than their performance in the audio+picture condition. Evidence of the redundancy effect was not found for either group. For the dyslexia group, performance in the text+audio+picture condition was similar to the performance in the audio+picture condition. Taken together, these findings suggest that college students with dyslexia may benefit most from multimodal instructional designs which include an audio component, regardless of whether the audio component is redundant with printed text or is presented alone. The benefit of audio presentation for these students was also supported by the eye gaze data. Specifically, when audio was provided, the students in the dyslexia group spent more time on the picture area than their peers. In addition, instead of frequently moving between the picture and the text areas, the students' eyes stayed in the specific area to process the information presented in the picture.

Implications for Practice

Several educational implications can be drawn from these findings. First, the current data show that the presence of pictures is not enough to ameliorate reading differences between students with and without dyslexia. Students with dyslexia are often believed to have strong visual-spatial skills (Ramus, 2003 for review), so it may be logical to assume that learning is enhanced when text is augmented by pictures. The present study did not find evidence to support this argument. One explanation for this is that students do not automatically know how to process information presented in visual forms (Yeh & McTigue, 2009). Winn (1994; 1987) warned that education's verbal bias could hinder students from developing their abilities to process non-linguistic visual representations. Recent research has shown that explicit instruction in how to process non-verbal information is necessary. Bergey, Cromley, and Newcombe (2015), for example, trained high school teachers how to interpret individual diagrams and how to connect diagrams with text. The training increased comprehension of diagrams of both high-achieving and low-achieving students, but was more effective for the low-achieving students. A second approach is to teach students specific strategies. Kombartzky, Ploetzner, Schlag, and Metz (2010), for example, taught students several strategies for learning through multimedia animated formats including identifying important pictures, circling important words and regions in pictures, and describing the relationship between pictures and words. Students who learned the strategies outperformed students who were provided the same material but did not learn the strategies.

Second, the audio presentation was most beneficial to students with dyslexia. Previous studies have mainly focused on exploring best ways to improve students' reading skills; however, mastering content material is as important as mastering reading skills, particularly for secondary and postsecondary students. Milani, Lorusso, and Molteni (2010) provided audiobooks to adolescents with dyslexia. Five months later, students who were provided with the audiobooks improved not only in reading accuracy, but also in emotional-behavioral problems and in motivation and involvement in school activities. Even though more studies are needed to help understand the best ways to use text-to-speech technology and audiobooks (e.g., frequency of use of audio materials), it is clear from the current study, and from other research, that audio material improves dyslexic students' learning and comprehension of content material. Students benefit from explicit instruction on using and accessing alternative media and technology.

Herein lies the study's utility for college disability service providers. Audio presentation of academic content, when coupled with images, was shown to benefit students with dyslexia. At the same time, the typical readers' learning was not hindered by this combination. Designing instruction in this manner appears to afford educational benefit, then, to a wider swath of students. Faculty who design instruction this way from the outset can work more efficiently by not having to replicate instruction using multiple modalities if required by a student's accommodations. This makes for smarter work. Even though disability service providers are not charged with course design or instruction, they can provide in-service experiences for faculty that could include effective teaching strategies for those who learn differently in addition to traditional information on legal aspects of learning accommodations. While faculty will likely differ in the uptake of such strategies (Park, Roberts, & Delise, 2017), most will conceivably welcome the direction in improving the inclusiveness of their instruction.

Faculty are experts in their field but are rarely trained in pedagogy (Brownell & Tanner, 2012), especially the pedagogy of those who learn differently. Many fields have called upon faculty to become more well-versed in evidence-based strategies in teaching and learning; however, time is one of the most frequently cited barriers to improving teaching practice (Collinson & Cook, 2001). By providing in-service experiences to faculty on more inclusive design, such as the Universal Design Initiative (Association on Higher Education and Disability, 2017) which is purposed to increase the inclusiveness of higher education environments, disability service educators can educate faculty on the front lines on more efficient (i.e., time-saving) teaching strategies that meet the learning needs of those with and without disabilities.

Limitations and Future Directions

Further research is needed to specify ways in which multimedia instructional designs affect learning, especially in terms of how multiple representations of a concept are processed in students with learning difficulties. The present study explored how different combinations of media affected students' learning, but the unique effects of each representation were not disentangled. In the future, audio-only or text-only can be compared to audio+picture, text+picture or text+audio+picture conditions, which could clarify the unique effects of different representations. Further research should differentiate the function of the pictures in the presentation. In the current study, the pictures described information presented in text. Thus, the function of the pictures was to aid students' memory and comprehension of text information. To further explore the role of competing visual attention and the redundancy effect, it would be interesting to design a study in which pictures present information that does not simply support but rather extends the information provided in the written text. Finally, pacing and order of comprehension questions should be investigated further. The current study presented each PowerPoint slide in average eight second intervals and presented comprehension questions after students completed viewing the material. However, presenting comprehension questions first might encourage students to selectively attend to the key information on the slides. A self-pacing experiment would also allow students to advance the slides without predetermined time constraints. This may be especially important for students with dyslexia who commonly present with reading speed deficits. It is suspected that allowing students additional time would improve performance on retention questions, especially in multimedia formats that do not include audio narration.

In the current study, eye tracking is used to monitor eye gaze, with minimum intrusiveness, as students view on-screen information. The use of eye tracking methodology is based on the belief that perceptual processes index underlying conceptual processes (e.g., longer fixation time on a specific area reflects longer processing time of that area; eye-mind hypothesis, Just & Carpenter, 1980). In his review of the literature on dyslexia over twenty years, Rayner (1998) stated that eye-movement difficulty is not a cause of dyslexia, but a symptom reflecting underlying impaired mechanisms. After scrutinizing the evidence for and against sensory theories of dyslexia, Goswami (2015) also concluded that the sensory deficits may result from the effects of reduced reading experience on the brain. However, she also accepted the possibility of sensory dysfunction in dyslexia and suggested that future studies, such as longitudinal studies of sensory processing, beginning in infancy, will contribute to remediation of dyslexia.

Conclusion

Multimodal instructional designs can enhance learning outcomes for students with dyslexia. The findings suggest that the addition of pictures is not as beneficial as the addition of an audio recorded reading of the text. Moreover, when audio is paired with pictures, students with dyslexia focus attention on accompanying pictures and can learn content material as easily as their peers with typical reading skills. To support students' success, educators, disability service providers, and instructional designers should be aware that different combinations of multimedia input can have different effects on learning depending on the specific learning outcomes as well as the students' reading ability. All students would benefit from specific instruction in how to comprehend individual representations and connect different types of representations.

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Table 1

Characteristics of Students with Dyslexia and Students with Typical Reading Skills

	DR Group Mean *(SD)*	TR Group Mean *(SD)*	*F* Statistics (1,155)	*P*-value
Age (years)	21.83 (6.40)	21.66 (4.64)	0.04	.85
Education (years post high school)	2.57 (1.85)	3.03 (1.62)	2.62	.11
TOWRE Total Word Reading Efficiency (SS) (average = 100)	76.89 (7.97)	98.53 (8.44)	241.91	< .0001
WJ-III-COG verbal ability (SS) (average = 100)	89.29 (11.02)	96.03 (10.17)	14.62	.002
TOMAL-2 Visual Sequential Memory (SS) (average = 10)	9.74 (2.72)	10.04 (2.53)	.49	.48
Prior knowledge questionnaire (maximum score = 12)	5.29 (2.01)	4.88 (1.75)	1.77	.19

Note. DR = dyslexia (*n*= 54); TR = typical reading skills (*n*= 103); TOWRE = Test of Word Reading Efficiency; WJ-III-COG = Woodcock Johnson III Test of Cognitive Abilities; TOMAL-2 = Test of Memory and Learning, second edition), SS = Standard Score.

Table 2

Summary of Analysis of Covariance and Bonferroni Post-Hoc Test for Retention Test

	Dependent Variable: Retention Test Score				
Factor	*MS*	*df*	*F*	*P*-value	η_p^2
Reading group	21.87	1, 2.06	.57	.52	.22
Presentation type	16.68	2, 2.00	.20	.83	.16
WJ-III-COG Verbal ability score	14.55	1, 150	2.41	.12	.02
Reading group * presentation type	41.77	2, 150	6.91	.001	.08

	Bonferroni Post-Hoc Test		
	df	*T*	*P*-value
Text+picture (DR score < TR score)	150	− 4.15	<.0001
Audio+picture	150	0.77	.44
Text+audio+picture	150	− 0.11	.91

Note. MS: mean square; df: degree of freedom; DR = students with dyslexia; TR = students with typical reading skills.

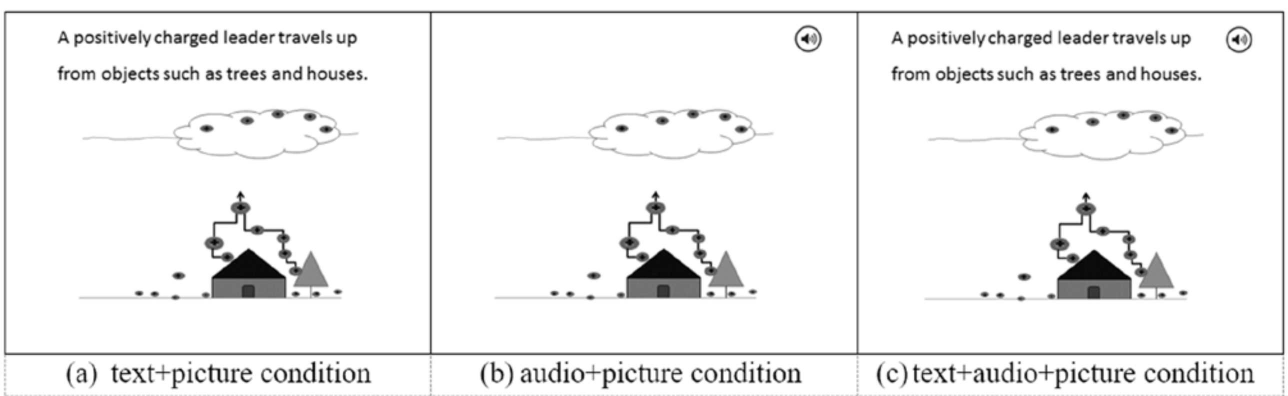

Figure 1. Examples of slides from each condition.
Note. Speaker icon in the audio+picture and text+audio+picture conditions was not presented in the experiment.

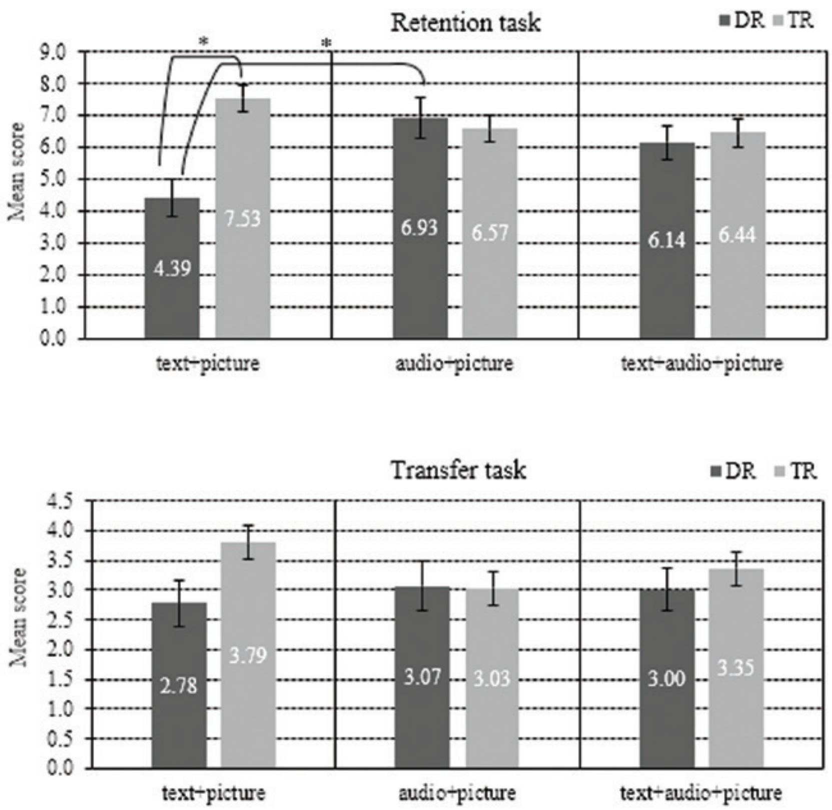

Figure 2. Mean scores for the reading groups on the retention (top) and transfer (down) tasks. Error bars represent standard error of the mean. DR = dyslexia group, TR = typical reading skill group, * $p < .05$

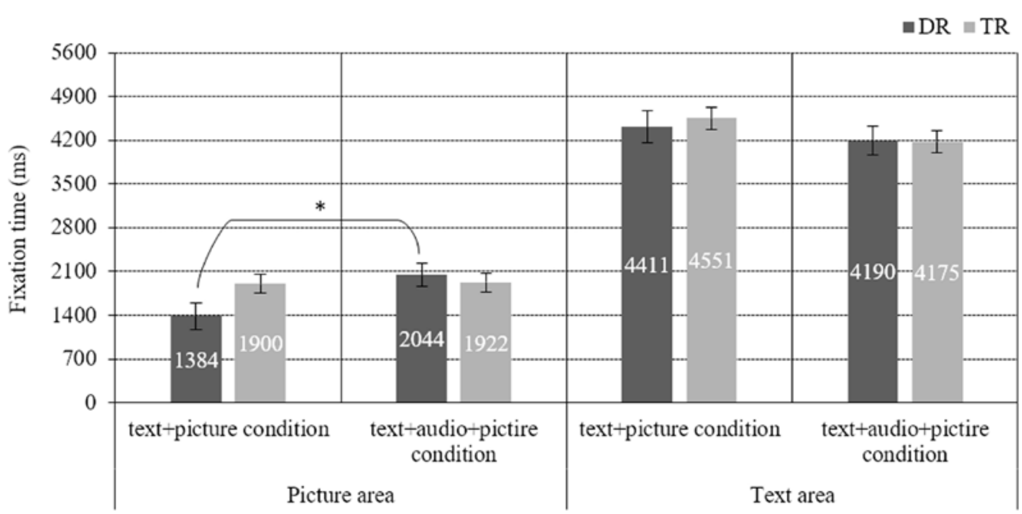

Figure 3. Eye fixation times (milliseconds) for the reading groups on the picture and the text areas. Error bars represent standard error of the mean. DR = dyslexia group, TR = typical reading skill group, * $p < .05$

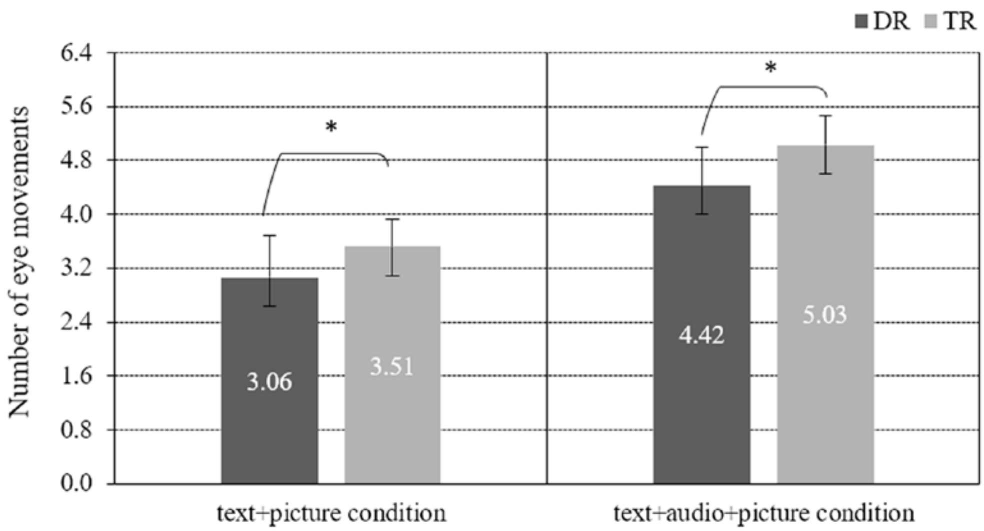

Figure 4. Eye movements between the text and picture areas for the reading groups. Error bars represent standard error of the mean. DR = dyslexia group, TR = typical reading skill group, * $p < .05$