An investigation into the effects that digital media can have on the learning outcomes of individuals who have dyslexia

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Abstract
The effects that media can have on task performance have been greatly debated over the years. Whilst agreement has begun to emerge on the effects media has on cognitive performance, little is understood about the relationship between such media effects and individual differences such as individuals who have dyslexia. This paper presents findings from a study that investigated the effects computer-based media can have on the learning outcomes of individuals who have dyslexia compared to those who do not have dyslexia. The purpose of the study was to obtain data that informed the development and design of e-learning and distance learning materials for universal use. The research process was based on Dual Coding Theory and refined by current theories on dyslexia. Findings from the research are intended to help academics and providers of e-learning materials to improve the design and delivery of their learning contents.

Introduction
The work covered in this paper was conceived from an initial study we had carried out into the effects computer-based media can have on the learning outcomes of students (Alty, 2002). The findings from the initial study showed that computer-based media could have a significant effect on the learning outcomes of learners. Furthermore, media can have a significant effect on the learning outcomes of learners with various learning styles when presented with different media combinations. These findings from the initial study are also supported by an earlier pilot study (Beacham et al, 2002). The evidence from the initial study shows that using a ‘one-size-fits-all’ approach to developing learning materials is more problematic than experts lead us to believe (Baggett, 1989; Kozma, 1991; Cross, 2000; Moreno and Mayer, 2001; TechDis, 2002). The type of computer-based media used in e-learning materials can have significant consequences on the amount of information retained and understood by students depending on the types of learning style they adopt (Alty, 1999; Najjar, 1996).

Taking part in the initial study was a small number of dyslexic students. The findings of our initial study suggest that the most effective media combination for non-dyslexics, when learning course materials are delivered in the form of a computer-based presentation, seems to be sound and diagrams. However, there was no obvious effective media combination for those who were dyslexic. Our experiments suggest that different computer-based media combinations affect learners who have dyslexia differently to non-dyslexic learners. This was unexpected, since the learning materials used consisted of both verbal and nonverbal contents. Whilst we would have expected the dyslexic students to have problems with text alone, it was not expected they would have problems with text and diagrams or with sound and diagrams. Interestingly, some dyslexic students obtained higher scores when having information presented as text alone than with text and diagrams. The findings from our initial study seems to suggest that information presented using text and diagrams for non-dyslexic learners may not be the most efficient way of presenting information to dyslexic learners. Furthermore, the results from the dyslexic sample could not be completely explained by our underlying theoretical framework i.e., Dual Coding Theory (Paivio and Begg, 1981). A full account of the initial study has been given by Alty (2002).

Findings from the initial study have raised a number of new and important issues. First, how might computer-based media affect dyslexics differently to non-dyslexics, and second, should e-learning...
materials be designed specifically for dyslexics. Although there were only a relatively small number of dyslexic subjects in our initial study, there are indications that varying the combinations of computer-based media affects the learning outcomes of dyslexic students in a different way to those of non-dyslexics. If these results are shown to be conclusive, serious consideration needs to be taken as to the way e-learning materials are designed and delivered.

Since carrying out this study, we have also become aware that little research has been carried out into the effects that computer-based media have on learners who have dyslexia. In the light of the introduction of new legislation, i.e., the Special Educational Needs and Disability Act (SENDA, 2001), it is clear that a deeper understanding of such media effects is needed.

The initial findings from our studies provide tentative evidence supporting the need for further research to be carried out into whether media used in teaching and assessment materials can be produced for both dyslexic and non-dyslexic learners. At present, there are two opposing positions. There are those researchers who believe a single set of teaching and learning materials can be designed for both dyslexic and non-dyslexic learners, and those who believe that different teaching and assessment materials should be produced for dyslexic learners if they are to be given the best opportunity to succeed in Higher Education (Seelman, 1998; Singleton, 1999; DRA, 2001; Rose and Meyer, 2002). However, it does seem from our observations that very little extra learning material is being produced for dyslexic learners and none concerning assessment.

We therefore set up a more detailed study, centred entirely on addressing the effects that computer-based media can have on learners who have dyslexia. This research aimed to help to clarify whether the current philosophy for designing multimedia contents for all types of learner is justified. Before explaining how we went about carrying out the study, the following section clarifies what is meant by dyslexia and outlines the theoretical framework used.

**What is dyslexia?**

For the purpose of this study, the following definition by Thomson and Watkins (1990) has been used to describe dyslexia:

> "Developmental dyslexia is a severe difficulty with the written form of language independent of intellectual, cultural and emotional causation. It is characterised by the individuals’ reading, writing and spelling attainments being well below the level expected, based on intelligence and chronological age. The difficulty is a cognitive one affecting those language skills associated with the written form, particularly visual, verbal coding, short-term memory, order perception and sequencing."

This definition is particularly fitting because it is derived from a cognitive perspective and is centred not only on children, but also on adults who have dyslexia. This definition was also felt to be particularly attuned to verbal and nonverbal modalities described in Dual Coding Theory.

Adult dyslexics tend to have a lack of automaticity in single word decoding and phonological processing (Nicholson and Fawcett, 1990; Fawcett and Nicholson, 1998). They also have weaknesses in other cognitive abilities, not only those related to language-based tasks. These can include:

- Short-term memory;
- Processing sound;
- Co-ordination and motor skills;
- Visual processing.

As a result, adult dyslexic learners often have difficulty performing many of the following activities:

- Reading and writing;
- Organising and timing;
- Remembering sequences of items and concentrating for long periods;
- Learning and understanding written or spoken words;
- Recognising and recalling written or spoken words;
- Finding and navigating textual information.

E-learning materials can cause the same difficulties for adult dyslexic learners as do paper-based materials. Although it has been shown that e-learning materials can help dyslexic learners, these
difficulties can still arise when carrying out particular tasks. Using these learning materials, dyslexic learners will still:

- Reread textual material;
- Read slowly;
- Misread words;
- Lose their place;
- Find it difficult to focus on the screen/page;
- Find unfamiliar vocabulary difficult to learn;
- Have difficulty with naming tasks;
- Have difficulty making connections between information represented by words or speech sounds;
- Have difficulty learning sequences of words or symbols;
- Be uncomfortable due to visual perceptual difficulties;
- Reverse letters, words and even phrases.

It is also a misconception that dyslexic learners only have problems with reading and writing of words. There is growing evidence that suggests some dyslexic learners have difficulties with other forms of symbolic representations, such as Mathematics (Vollutino et al, 1975; Gillis et al, 1995; Lindamood et al, 1997; Chinn and Ashcroft, 1998; Henderson, 1998; Butterworth, 1999). Whilst studies varied, Gillis et al (1995) found that 50% to 100% of dyslexics also have some mathematical difficulties.

Mathematical problems experienced by dyslexic students in Higher Education include:

- Poor long term memory for retaining number facts and procedures, consequently poor numeracy skills;
- Theorems and formulae are difficult to retain, recall and apply;
- Mathematical procedures and sequences of operations are difficult to perform;
- Overload occurs more frequently and the student is forced to stop;
- Holding various aspects of a problem in mind and combining them to achieve a final solution;
- Multi-step problems making students frequently lose their way or omit sections;
- Problems in sequencing complex instructions, and past/ future events;
- Difficulties reading the words that specify the mathematical problem, especially if the problem is embedded in large amounts of text;
- Slow reading, misreading or not understanding what has been read;
- Substituting names that begin with the same letter e.g., integer/ integral, diameter/ diagram, classify/ calculate;
- Problems remembering and retrieving specialised mathematical vocabulary;
- Problems associating the word with its symbol or function e.g. relating ‘integration’ to its symbol and knowing what procedure to carry out;
- Visual perceptual difficulties/ problems and reversals, e.g., 3/E or 2/5 or +/x;
- Presentation of work and positioning on the page;
- Problems transferring between mediums, e.g. question paper to computer or calculator;
- Making copying errors and slow information processing means that students have few and incomplete notes;

Dyslexic learners will also tend to perform inconsistently day to day and fail to equate the question wording with their knowledge of the subject. For many years, multi-sensory approaches have been advocated in order to help dyslexic students learn subjects such as mathematics (Pumfrey and Reason, 1991; Miles and Miles, 1999; Hunter-Carsch and Herrington, 2001). In spite of the success of this approach, and contrary to expectation, dyslexic learners can feel overloaded by multi-sensory presentation (Mortimore, 2003, pp. 271). Our study centred on trying to find the optimum combination of media for dyslexic learners.

One particular problem with e-learning materials is that whilst they may contain multimedia, they do not strictly comply with conventional multi-sensory approaches to help dyslexic learners. The element of touch is not available. Furthermore, dyslexic learners are often prevented from applying active reading strategies that can help to remove or reduce dyslexic difficulties. Findings from our previous study suggest that due to the effects computer-based media can have on learning outcomes, such media might also exacerbate the difficulties dyslexics have, if the e-materials are inappropriately designed and delivered. This raises the issue of whether e-learning materials should be developed where information is represented using media for all sensory forms (including touch) or whether specific types of medium
need only be developed according to a particular learning task (Bissell et al, 1971; Clark, 1994; Cobb, 1997).

**Theoretical framework: Dual Coding Theory (DCT) and dyslexia theory**

In our previous studies, DCT has provided a useful framework for explaining how particular media come to be more effective than others (Alty, 2002; Beacham et al, 2002). Dual Coding Theory (Paivio, 1986) assumes a relationship between symbolic systems and sensory motor systems. The theory suggests that there are clear distinctions between the internal representations of Symbolic and Sensory-motor events. The stored versions of visual, verbal, and haptic events retain the modalities of these events. For example, in the visual modality there are printed words and images. In the auditory modality, there are spoken words and sound events. Lion can be stored as an image of a lion, the word “lion”, or both but within distinct systems. Of major importance is the verbal/nonverbal distinction. The verbal and non-verbal processing systems are assumed to be functionally independent, though there are cross linkages between the two. If the Dual Coding Theory is relevant, then the recall of material will be affected by the way it is presented. According to Paivio’s (1971, 1991; Clark and Paivio, 1991) Dual Coding Theory, information is processed through one of two generally independent channels. One channel processes verbal information such as text and audio and the other channel processes visual information such as diagrams, animations and photographs. Paivio also advocates two different types of internal representational unit: ‘imagens’ for mental images and ‘logogens’ for verbal entities. Logogens are organized in terms of associations and hierarchies while imagens are organized in terms of part-whole relationships. Three types of internal processing are identified: representational - the direct activation of verbal or non-verbal representations; referential - the activation of the verbal system by the nonverbal system or vice-versa; and associated processing - the activation of related presentations within the same verbal or nonverbal system. Whilst it is agreed that a given task may require any or all of the three kinds of processing, it is not clear what and in which order people with different learning styles activate these types of processing. Furthermore, the effect on the learning outcomes of students with different learning styles is not clear when different media combinations are used. Studies by Paivio and others (Baggett, 1989; Kozma, 1991) suggest that by choosing an appropriate combination of media, learning outcomes can be improved. For example, information that uses verbal and relevant visual illustrations will be likely to be learned better than information that uses text alone, audio alone, a combination of text and audio, or illustrations alone.

Since 1971, Dual Coding Theory has been used as an explanation for the effects of multimedia information on learning in a number of studies (Paivio, 1971; Baggett, 1989; Kozma, 1991; Moreno and Mayer, 2000). Many researchers agree that Dual Coding Theory gives a reasonable explanation for the results of a large number of studies of multimedia learning (Najjar, 1996). The theory is particularly useful because it explains the way information is processed by human beings and relates this to visual and verbal styles of learning. A number of principles and guidelines for designing multimedia have since been derived from Dual Coding Theory and applied to the development of computer-based learning materials. What is more, this theory seems to be as relevant today as it was some 30 years ago, in spite the advancements in new technology and changes in education (Paivio, 1991; Sadoski and Paivio, 2001).

However, DCT has been unable to account fully for the individual differences between dyslexics and non-dyslexics. Whilst DCT has attempted to explain how different types of media affect individuals with disabilities, such as blindness and deafness, there has not been the same clarification given by DCT for those who have dyslexia (Paivio and Begg, 1981). One possible reason for this is that dyslexia is a subject that is still not fully understood.

In order to help refine DCT, we have reviewed recent literature on dyslexia theory. There are clear similarities and common areas between DCT and dyslexia theory. Many of the studies about dyslexia reported in the literature use similar methodologies and tests to those reported in the DCT literature. Whilst the dyslexia studies contain tests to explain possible differences between dyslexics and non-dyslexics, DCT uses the test as a way to explain mental processes in human learning and memory (Paivio, 1991; Sadoski and Paivio, 2001; Vellutino et al, 1975). Many of the factors measured are also similar, such as word/non-word recognition, paired associate learning, sequential recall (digit span test), word frequency/familiarity, object naming and reading speed and fluency. Interestingly, many of the exercises developed as part of dyslexia screening tools are also found in DCT. One area common to both DCT and Dyslexia theory is that some of the difficulties dyslexics experience can be related to dual coding processing tasks, such as inefficient working memory. This is not to say that dual coding
processing tasks cause dyslexia. There are a growing number of researchers who have reported a connection between dual coding processes and dyslexic difficulties (McLoughlin, 2001; Clarke and Paivio, 1991; Singleton, 1999; Snowling, 2000; Stein, and Talcott, 1999).

McLoughlin (2001) suggests that, “An inefficient working memory will clearly undermine skill acquisition and learning. Describing dyslexia in this way [as a working memory deficit] can help explain both the persisting writing language difficulties as well as the broader problems experienced by adults; the notion of dual processing being central”. Stein and Talcott (1999) argue that most dyslexics have both visual and phonological problems. Such problems result from lowered visual and auditory sensitivity skills required for reading. Invariably, learning requires visual analysis of words and symbols (orthography), together with auditory analysis of the sounds of words (phonology). Stein and Talcott report that visual and auditory sensitivity plays a major role in determining how well orthographic skills develop and auditory sensitivity helps to determine how well phonological skills develop. Snowling (2000, pp.175) reports that, “there is a growing body of evidence suggesting that dyslexic readers as a group show elevated thresholds for the detection of stimulus dimensions in both visual and auditory modalities, particularly those that involve temporal resolution. There is also some suggestion that the performance of dyslexic readers on these sensory processing tasks correlates with their reading skill”. Snowling goes on to argue that, “an important question for future research is how these affected individuals differ from those who show perfectly normal performance on sensory processing tasks”.

**Experimental study**

To ascertain the effects of using multimedia information on the learning of students who have dyslexia, e-learning material from the original study was presented to three groups of dyslexic students. One group was shown a version of the material containing sound and diagrams, a second group was shown a version containing text and diagrams and a third group was given a version containing text alone. Data collected from each group were then compared. The remainder of this section provides further details of the methodology, the instruments, the materials and the sampling techniques used in the experiment.

**Methodology**

The methodology used to obtain experimental data is illustrated in Figure 1. The methodology used in our previous studies was refined slightly before being used in this study in order to take into consideration experimental and ethical issues. Each participant started by completing a pre-questionnaire to obtain his or her personal details, such as their name, age, gender, department, course, qualifications, how recently they had been assessed for dyslexia and by whom. Each participant then completed a Learning Style Inventory.
This was followed by each participant completing a number of cognitive assessments using the Lucid Adult Dyslexia Screening software (LADS) and a Visual Perceptual Problems Inventory (VPPI). Whilst each participant was being assessed, the participant’s data from the Learning Style Inventory was analysed and used to place him or her in one of three groups according to his or her Active/Reflective learning style. As far as possible, each group was balanced according to gender and learning styles.

Before showing each participant the learning material, each was given a pre-test. This was followed by a ten-minute presentation on statistics covering hypothesis testing. The media combination he or she was shown was determined by the group each participant was placed in. For example, those participants placed in Group A were shown ‘Presentation A’ containing sound and diagrams, Group B were shown ‘Presentation B’ containing text and diagrams, and Group C were shown ‘Presentation C’ containing text alone. Then after seeing the presentation, each participant was given a post-test.

With the exception of the instruments used to assess cognitive skills and the pre-test, the methodology, learning materials and theoretical framework in the study are the same as those used in the previous studies (Alty, 2002). It was also decided to pay each participant ten pounds for taking part in this study.

**Instruments**

The test instruments employed in this study were a revised version of the Felder-Silverman Learning Style Model inventory on learning styles (by Richard M. Felder and Barbara A. Solomon), a dyslexia-screening tool (by Lucid Research Ltd), a visual-perceptual problems inventory (by Dr Chris Singleton), and a pre-test questionnaire and a post-test questionnaire.

**Learning style inventory**

The learning style inventory was used as part of assessing whether different media combinations can have an effect on dyslexic learners who have a preferred learning style. The learning style inventory consisted of 44 multiple choice questions about a learners preferred way of learning and a score sheet for calculating a learners preferred style. The inventory categorised each participant into four broad learning styles: Active/Reflective, Sensing/Intuitive, Visual/Verbal and Sequential/Global.

- Active learners prefer to learn by doing and tend to rush into learning situation, whilst
- Reflective learners prefer to think about the situations on their own before starting.
- Sensing learners prefer learning facts and solving problems by well-known methods, whilst
- Intuitive learners prefer to discover possibilities and relationships. Initiative learners also tend to be more comfortable with abstractions and mathematical detail.
• Visual learners prefer to learn using pictures, diagrams, flow charts, time lines, films and demonstrations, whilst Verbal learners prefer to learn using words – written or spoken.
• Sequential learners prefer to learn in linear steps, with each step following on logically from the previous one, whilst Global learners prefer to absorb the material randomly without necessarily seeing connections. Global learners also tend to learn in large jumps.

The inventory chosen was selected after reviewing numerous different inventories that are available in electronic and/or paper form. We discounted inventories that: (a) would have taken too long to complete in a classroom situation; (b) were aimed at children (i.e. pre-sixteen); (c) were specifically related to visual, auditory, tactile, since we decided these will reveal little new information or interest to us in general; and (d) were difficult to fill-in and could easily be skewed by erroneous answers. Particular care and attention was also taken to ensure that the dyslexic participants did not experience the types of difficulties reported when performing multiple-choice exercises (DRA, 2001). The Felder-Silverman Learning Model was used for a number of reasons. It did not contravene the criteria given above and the inventory has been tested and validated, and shown to produce reliable results (Felder, 1993).

**Cognitive skills assessment**

It was important that we assessed the types of cognitive skills that have been shown to differ between dyslexic and non-dyslexic individuals (Singleton, 1999; McLoughlin, 2001). As part of the MEDIA methodology, the Lucid Adult Dyslexia Screening (LADS) program, a computer-based program for screening adult dyslexia, was used to assess each participant’s cognitive skills (Singleton, 1999). The LADS software was used as part of assessing whether different media combinations can have an effect on dyslexic learners who have different cognitive skills.

Before settling on LADS, we considered a range of other alternative methods for assessing cognitive skills of dyslexic participants. These ranged from sending participants for an independent assessment by an expert to developing our own assessment instrument. It was felt that sending participants for an independent assessment would have been expensive and time consuming for this particular project. In contrast, it was felt that developing our own assessment instrument would also have been time consuming and would have required specialist skills. We therefore chose from a number of off-the-shelf instruments that could meet our requirements. The LADS software was chosen after reviewing other alternative off-the-shelf instruments, such as ‘Instines’ (by Steve O’Brien, Adult Dyslexia Access) and Dyslexia Adult Screening Test (DAST) – a conventional paper-based approach (Fawcett and Nicholson, 1998).

The LADS software consists of four tests: a reasoning test, a word recognition test, a word construction test and a memory test. These tests account for difficulties that are reported to stay with dyslexics throughout their adult life. The software has also been empirically validated in a number of studies set up to test the software (LADS, 2002). Overall, the four tests measure spatial and relational reasoning, phonological deficits, lexical access and short-term memory.

**Visual perceptual problems inventory**

Since dyslexic learners can have visual perceptual problems (Stein and Talcott, 1999) and that the LADS software was unable to account for this, the VPPI instrument was used. Complementing the LADS software with the VPPI helped explain some of the difficulties that each participant experienced during each LADS test exercise.

**Pre- and post-test questionnaires**

The pre- and post-test questionnaires were paper-based and consisted of sixteen open-ended questions. The questions were carefully crafted to assess the participants pre- and prior knowledge associated with the learning material contained in the presentations. Care and attention was taken to ensure that the answers to the questions were present within the presentation regardless of which combination of media was given. For each question, on both the pre- and post-tests there was also a field asking participants to identify whether they knew the answer before seeing the presentation, whether the presentation helped them to recall the answer, or whether they had not known the answer before seeing the presentation. This was intended to give a subjective measure of their previous knowledge.
Learning materials
The learning materials used in the original study (Alty, 2002) were used again so that a general comparison could be made. The materials, which ran for ten minutes in duration, was developed in order to help assess the effectiveness of different combinations of media. The materials were developed using Macromedia Flash 5 and was about hypothesis testing and the use of statistics in experimental evaluation. The subject area of statistics was selected because it was felt that most students would have little previous knowledge about this topic and those students that did have previous knowledge about it often found the topic difficult. The aims and objectives of the materials were first defined and used to produce a series of ‘messages’. These messages represented key points that a student needed to learn from the presentation. The messages were then represented and replicated in a textual, visual and audio form. Three copies of the material were then produced as presentations. Presentation 1 presented the topic using text and diagrams, Presentation 2 using text only and Presentation 3 using sound and diagrams. To ensure that the only factor that changed was the media combination, the three presentations ran for the same length of time. Each presentation was then published in an executable form on a high specification laptop computer. Where possible, care and attention were taken to reduce the effects of environmental factors. For example, one of the main environmental factors that needed to be controlled was external and unnecessary noise/sound particularly during the experiments where participants were given the presentation containing Sound and Diagrams. It was also important that a suitable person was chosen to provide the audio because learners can find some people’s voice difficult to listen to.

Results
Thirty students participated in the study. The sample consisted of participants aged between 18 and 36. Of the participants, 13 out of 30 had A-level Maths, 13 had A-levels but not in Maths and the remaining 4 had alternative qualifications such as a BTEC HND.

The participants were from a variety of courses taught at Loughborough University. The majority of dyslexic participants were taking courses that tended to be predominantly practical and creative, and required less reading and writing than subjects such as History, Law, English and Languages. Participants were from Computer Science (5), Design and Technology (4), Chemical Engineering (3), Art and Design (3), Social Sciences (3), Civil and Building Engineering (2), Mechanical and Manufacturing Engineering (2), Information Science (2), Human Sciences (2), Physics (1), Electronic and Electrical Engineering (1), Economics (1), and Business (1). Other researchers have also reported similar findings (Kirkham, 2000; Wolff and Lundberg, 2002). For example, Kirkham (2000) reported that language subjects such as Linguistics tend to be the least attractive to dyslexic students. In her study, Art and Science subjects were most popular with dyslexic students (approximately 30%), followed by Law (8%) and Medicine (5%). Interestingly, only 5% of dyslexic students were attracted to the subject of Education.

Figure 2 show the types of learning styles dyslexic participants preferred. For example, in the case of Figure 2 there were two participants who possess a strong Active learning style preference (11a and 9a), nine who possessed a moderate Active learning style preference (7a and 5a), and eleven who possessed a mild Active learning style preference (3a and 1a).
With a few exceptions, the distribution of each type of learning style was shown in broad agreement with the distribution obtained in the previous study (Alty, 2002). There was a small difference regarding the preference of visual learners. In this study, the results show that the dyslexic participants possess a strong visual preference. This visual preference seems to be stronger than that of the non-dyslexic participants in our previous study. This was to be expected since dyslexic people do tend to be talented in the areas of creativity and visual thinking (West, 1997; Mortimore, 2003, pp. 80).

There is also a small difference in the preference for Sequential/Global learning styles between this dyslexia study and previous studies. In the previous studies, participants’ preferences were skewed towards sequential learners. In this dyslexia study, dyslexic participants were skewed towards global learners. Further research would need to be carried out in order to assess whether there is a significant difference. However, this seems to support Mortimore’s findings that suggest that dyslexic learners are inclined to focus more successfully upon the outline of any topic rather than its details and sequences of information (Mortimore, 2003, pp. 116).

Assessments for dyslexia
All the participants in the sample reported having dyslexia. The data collected by the LADS software further supported this position. Since carrying out the study, we have also learnt that within the last two years all the participants have been assessed for dyslexia and have been confirmed as having dyslexia by independent experts. However, at the time of carrying out the study, we were unable to obtain each participant’s assessment report.

Pre-test and post-test scores
The results show from the pre- and post-tests show that the majority of participants improved their score. Only two participants obtained post-test scores that did not improve from their pre-test. The results provide no evidence to suggest that participants with a poor previous knowledge of Statistics improved more than those with good previous knowledge and visa versa.

Learning style characteristics across media groups
The results obtained from the Learning Style Inventory show that the majority of participants preferred an Active learning style (22) to a Reflective learning style (8). The majority of participants also preferred a Visual learning style (29) to a Verbal learning style (1). However, the participants’ preferences were less skewed between Sensing (18) and Intuitive learning styles (12), and between Sequential (13) and Global learning styles (17).

We attempted to balance the groups across Sensing/Intuitive learners. However, unlike the previous study it was not possible to bring participants together in one group and then equally divide them into balanced groups. The results show that the learning styles of participants in the study were reasonably balanced given the circumstances in which each participant was assigned to a group.

Cognitive style characteristics across media groups
All dyslexic participants produced high scores within the reasoning test. The maximum any participant could score was five. In this case, the mean score for each media group was four. The test was based upon individuals' spatial and relational awareness and as expected, all dyslexic learners within the sample performed well when carrying out this type of task.

In contrast to the reasoning test participants performed poor for the word recognition, word construction and memory tests. Each of these three tests was scored out of nine. The results show that the mean score of each media group for the word recognition test was similar (the average being 4). There was a small variation in mean scores of each group for the word construction test and the memory test (average being 5 and 4 respectively). Analyses of results show no significant difference between each of the media groups for each of the tests. The results therefore suggest that three media groups were balanced according to the participants’ cognitive skills. The result would also suggest that each media group contained a similar sample of dyslexic participants.

Learning performance across media groups
When comparing the scores of participants across each of the media groups, the results show that the dyslexic learners in Group 3, who were given the Text Only presentation, improved their scores considerably more than those in Groups 1 and 2. Interestingly, Group 1, which was given the Sound and Diagram presentation, improved their scores the least. The results from this study suggest that Text
Only was the most effective media combination to use and that Sound and Diagrams was the least effective media combination to use. Figure 3 presents the participants’ mean scores for each media group in terms of pre-test, post-test and difference results. The results show that the presentation containing Text Only gave the highest difference between pre- and post-test scores and the presentation containing Sound and Diagrams the lowest scores. This result was also highly significant (p<0.013).

![Figure 3: Difference between pre- and post-test scores across each media group](image)

There was no significant difference in the pre-test mean scores between the media combinations. This result was also no significant difference in the post-test scores. Whilst these findings did not match our expected results, they did support the initial findings from the previous study.

**Learning performance of participants with different learning styles across media groups**

Figure 4 shows the difference in the mean scores obtained by the dyslexic participants within each group according to their learning style.

In all of the cases, except for Intuitive and Verbal learners, the Text Only presentation produced the largest increase in learning. Furthermore, in the majority of cases, the Sound and Diagram presentation produced the lowest increase in learning. Under further analysis, there are also some interesting and significant differences between the scores of learning styles. Of those participants who were either Active, Sensing, Visual or Global learners, the effect between the different media combinations was significance (p<0.031, p<0.002, (p<0.015 and p<0.040 respectively).

![Figure 4: Learning style scores across media groups](image)

There was no significant difference where participants were Reflective, Intuitive or Sequential learners. Due to the small number of participants who were Verbal learners, a significance value could not be calculated.

**Discussion**

The findings from our initial study led us to infer in this study that different combinations of media would have an effect on the learning performance of adult dyslexic learners (Alt, 2002). It was also
inferred that different media combinations would affect dyslexic learners differently to non-dyslexic learners.

**Key findings**

In general, the findings of this study support the above hypothesises. The results from this study offer the following findings:

- Firstly, different combinations of media, used to present e-learning materials to dyslexic students, lead to significant differences in their understanding.
- Secondly, dyslexic participants who prefer a particular learning style perform differently for different combinations of media.
- Thirdly, different combinations of media lead to differences in learning performance between dyslexic and non-dyslexic participants.

These findings also broadly agree with the ideas associated with Dual Coding Theory (Paivio, 1971; Paivio and Begg, 1981; Paivio, 1991; Sadoski and Paivio, 2001). Paivio reported that whilst in general using text and diagrams is more effective than text alone in conveying information, because of individual differences there are cases where this may not prove true. However, Paivio was unable to provide a clear explanation for this in terms of dyslexic learners.

**Explanation for findings**

One possible conclusion is that the e-learning materials used in this study place different cognitive demands on the dyslexic learners compared to the cognitive demands of non-dyslexic learners in the original study. This results in them recalling more information when presented with text alone. The media combinations may have exacerbated the difficulties dyslexic learners experience due to their different level of cognitive skills, learning style preferences, competence and experience. For example, the presentation containing sound and diagrams may have resulted in the retention of visual nonverbal information, but very little retention of the auditory verbal information. The presentation containing text and diagrams may have resulted in little retention of the visual verbal and nonverbal information because of a split-attention effect (Sweller et al, 1998). This effect might have exacerbated the difficulties dyslexic learners experience due to their skills being less fluent, more demanding and more error prone (Peer, 2003).

Finally, the text alone presentation may have resulted in the most retention because:

- There was a reduced possibility of split attention and consequently a reduction in the switching of code modalities and cognitive overload.
- The auditory verbal information in the sound and diagrams presentation was made tangible and therefore could be seen.
- The small amount of switching between modalities in the text was integrated.
- The text alone presentation overall presented less information therefore allowing dyslexic learners to keep pace.
- There was more cognitive effort able to be applied to transfer and generalise the information by forming stronger and a greater number of referential and associated connections between existing and newly formed logogens and images.

The results obtained in the study seem to show that, because dyslexic learners possess different levels of cognitive skills (i.e., phonological, and STM) than non-dyslexics, they find various media combinations more difficult to process. Snowling (2000, pp. 37) suggests that such impairment in phonological coding restricts the number of verbal items dyslexics can retain in memory. Consequently, this has a knock-on effect in short term memory. Snowling (2000, pp. 39) also reports that dyslexic people also have difficulty retrieving verbal information from long-term memory, reducing the efficiency with which they can lean on integration processes.

In terms of Dual Coding Theory, it has been reported that dyslexia cuts across symbolic (verbal and nonverbal) and sensory (visual and auditory) modalities (Paivio and Begg, 1981, pp. 341). Based upon the findings of this study we find no evidence to disagree with this. The evidence does seem to suggest that different media combinations representing information in the form of different symbolic and sensory modalities can have an effect on the learning outcomes of dyslexic learners. For example, there was a difference in dyslexic learners’ performance between visual and auditory sensory modalities (Text and Diagrams vs. Sound and Diagrams) and there was a difference in their performance between verbal and nonverbal symbolic modalities (Text Only vs. Text and Diagrams). This could mean a weakness in the associative connections made between visual and auditory verbal modalities.
Furthermore, this could mean that there is a weakness in the referential connections between logogens and imagens - a similar argument proposed by Paivio and Begg (1981). Paivio and Begg (1981, pp. 341) report that in terms of people who have dyslexia, “sensory integration was confounded with symbolic integration”.

Overall, the finding that different combinations of media affect dyslexic students’ understanding is similar to the findings reported in our previous studies. In addition, on further investigation, we have found evidence that computer-based media affects the learning performance of dyslexic learners differently to non-dyslexics. In contrast to what was expected (i.e., that Text and Diagrams would be the most effective media combination to use, followed by Sound and Diagrams and finally Text Only), Text Only presentation seems to be the best combination of media. Furthermore, the Sound and Diagrams presentation resulted in dyslexic learners obtaining the poorest levels of learning. These results are contrary to the results for non-dyslexic learners obtained in previous studies. The results from this dyslexia study also support the initial unconfirmed findings of the original study regarding students with dyslexia.

In line with the previous studies we have carried out with non-dyslexic learners, the preliminary findings provide evidence that different combinations of media can have an effect on the learning performance of dyslexic learners who have different learning styles. However, the dyslexic participants who had a preferred Sensing learning style tended to perform better than those who preferred an Intuitive learning style, and of those dyslexic participants who were given the Text Only presentation, the participants that preferred a Sensing learning style performed better than those that preferred a Intuitive learning style. This result is different to the findings within our previous studies on non-dyslexics where non-dyslexic learners who preferred an Intuitive learning style performed better than those who preferred a Sensing learning style. In the case of dyslexic learners, in general our findings are in broad agreement with Chinn and Ashcroft’s findings (1998). Chinn and Ashcroft (1998) report that dyslexic students who are inaccurate intuitive learners are particularly at risk. Our results also support Chinn and Ashcroft’s findings that dyslexic learners who are sequential learners are also at high risk of failure of maths. However, under further examination it does depend on the type of media combination used as to whether our findings support those by Chinn and Ashcroft. We therefore have concluded that learning materials designed for non-dyslexic students with different types of learning style may not also support dyslexic students with similar learning styles and that the media combination used to represent mathematical information may be placing dyslexic students who have one particular learning style at more risk than others.

Our findings also show a striking difference between how participants actually performed and which combination of media they most liked. The majority of participants preferred the Text and Diagrams presentation. Furthermore, they found the Sound and Diagrams presentation the easiest to follow. It was even reported by some participants that the Text Only presentation was dull. Despite all this, the evidence seems to show that the Text Only presentation provided the most improved learning performance. Our explanation for this is that the pacing of each presentation and the switching between different types of media plays a major part when dyslexic students carry out learning tasks. This can also explain some of the difficulties dyslexic learners have with lectures – particularly in lectures where students only obtain one viewing of the information. If the material is presented too quickly and/or different types of media are changed without clear and obvious reasons, then dyslexic students will tend not to have learned as much as non-dyslexics. The pacing of the presentation and switching of the media can cause short-term memory problems for dyslexic students. Whilst lecture notes can help dyslexic students to recall what was covered in the lecture, they too can add problems. Following the notes and adding comment during the lecture entails much switching between media and incurs pressure on short-term memory, given the limited time available. Therefore, dyslexic students will still often spend many more hours in their own time going though the notes repeatedly.

Our findings should not be construed as saying auditory and nonverbal information should not be used in the case of dyslexic learners. It is imperative that different combinations of media are used and that current good practices are followed. However, there should be additional care and attention taken to reduce the amount of unnecessary cognitive effort placed on students. Not all information needs to be represented in every type of sensory and symbolic modality, if it is obvious that the learner has the necessary cognitive skills to understand the information. In other words, the aim is for the student to learn the contents and not be prevented/ distracted by the ‘carrier language’.
Limitations
This study has taken a step in the direction of defining the relationship between media, learning tasks and learners with special needs in Higher Education. It is possible of course, that other subjects and forms of media (such as video, virtual reality) with a more complex set of combinations may produce entirely different results. In addition, it is important to emphasise that methodological limitations in the research design limit our interpretations. Therefore, we are unable to make statistical comparisons between the results from the dyslexic and original studies in terms of whether dyslexic learners learnt more than non-dyslexic learners.

Implications
Overall, it appears that the media combination used in e-learning materials is an important factor not only for non-dyslexic learners but also for dyslexic learners. A reduction in the cognitive effort for non-dyslexic learners can result in an increase in cognitive effort for dyslexic learners. Since e-learning materials tend to be developed primarily for non-dyslexics this could increase:

- The stress levels of dyslexic learners
- The inability to build on dyslexic learners strengths
- The inability to recognise their own mistakes
- The costs of developing, delivering and supporting e-learning materials
- The inability to provide an inclusive learning environment
- The inability to provide accessibility and convenience for all learners

From the perspective of dyslexic learners, this can result in them spending even more time and effort struggling to learn than they currently experience using conventional approaches.

Conclusions
Findings from the dyslexia study have shown that different types of media combination can have an effect on the learning performance of dyslexic learners and that the effects the media have can be different in the case of non-dyslexic learners that have been presented with the same learning materials. Although we have demonstrated a difference in the effect media has on dyslexic learners to their non-dyslexic colleagues, we feel it is still too early to make any general conclusion. Further research is needed in order to substantiate these findings.

From our study it has become clear that not only are there theoretical links between DCT and dyslexia theories, but also the links can be expanded to multi-sensory approaches. There are numerous examples of multi-sensory approaches used to help dyslexic learners to read and write. Interestingly, whilst from a top-down perspective these approaches look to be multi-sensory, from a bottom-up perspective they can be analysed as separate or combinations of media. In essence, effective multi-sensory approaches can be underpinned by theories such as dual coding.

The approach outlined in this study needs to be replicated in other subject areas, as well as in using different approaches to e-learning in Higher Education and Further Education in order to construct a typology of learner performance in a variety of learning tasks and find ways of encouraging dyslexic students to reduce their stress levels before commencing with a learning task.

References


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