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DOI:
10.14236/ewic/HCI2022.11

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
Alghabban, W & Hendley, R 2022, Exploring the Effectiveness of Adaptation Based on Dyslexia Type and Reading Skill Level to Support Learners with Dyslexia. in E de Quincey, SI Woolley, M Ortolani, G Misirli, B Mandal, N Kanwal, J Mitchell & J Rooney (eds), *Proceedings of the 35th International BCS Human Computer Interaction Conference (HCI 2022)*., 11, Electronic Workshops in Computing (eWiC), ScienceOpen, pp. 1-10, 35th International BCS Human-Computer Interaction Conference, Keele, United Kingdom, 11/07/22. https://doi.org/10.14236/ewic/HCI2022.11

http://dx.doi.org/10.14236/ewic/HCI2022.11

Exploring the Effectiveness of Adaptation Based on Dyslexia Type and Reading Skill Level to Support Learners with Dyslexia

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E-learning has become a popular tool for helping people with dyslexia to improve their reading, as it provides interactivity anywhere and at any time. However, most traditional e-learning systems are designed for a generic learner, regardless of each individual's differences and needs. In this context, a successful e-learning system needs to consider the learner's individual characteristics – in particular, their dyslexia type and reading skill level. This can lead to a more appropriate learning experience and interaction. There is, however, a need to understand the value of this adaptation, particularly on the learning gain. This study contributes to research by bridging this under-investigated gap by evaluating the learning effectiveness of adapting material based on the learner's dyslexia type and reading skill. A controlled, between-subjects experiment with 47 subjects is described and the results presented and analysed. The findings indicate that adaptation based on the combination of dyslexia type and reading skill level results in significantly better short-term and long-term learning gains and greater learner satisfaction than non-adapted material. There is also evidence that this benefit transfers to learners' reading performance on unseen material.

Adaptive e-learning, Dyslexia type, Reading skill level, Learning gain, Satisfaction, Arabic, Dyslexia

1. INTRODUCTION

Recently, many researchers have focused their attention on electronic learning or 'e-learning'. It eliminates geographical constraints and increases access flexibility to learning resources to ensure 'learning for everyone'. Also, it can provide these resources in different formats, everywhere and at any time. Whilst e-learning has proven popular, several limitations have been identified. These limitations include a lack of interactivity, of learner control of the environment, of adaptive presentation formats, of learning navigation and of personalisation of educational materials. From this perspective, contextualising learning serves as a new paradigm for adaptive e-learning systems, which aims to solve these traditional limitations (Alghabban and Hendley 2020b). A system's ability to adjust its output in response to learner needs is often referred to as adaptivity or adaptation (Brusilovsky 2001). Adaptive e-learning systems aim to satisfy learners' needs by adapting the traditional learning approach to different learners' attributes, such as their personality, knowledge level and learning style. An adaptive e-learning system can customise the sequence of learning materials, change elements of the user interface or highlight important text, according to learners' characteristics.

Adaptive e-learning also opens an avenue for learners with reading difficulties (e.g. dyslexia) by considering their characteristics within an educational environment. For learners with dyslexia, characteristics such as their dyslexia type and their knowledge level are significant factors influencing their learning (Benmarrakchi et al. 2017b; Alghabban and Hendley 2020b). These can be incorporated into the learning environment to drive the personalisation of the learning experience. Many educational theorists stress that learners with dyslexia differ in their dyslexia type and symptoms, each with unique reading problems (Friedmann and Haddad-Hanna 2014; Alsobhi et al. 2014; Friedmann and Coltheart 2016). Further, several well-known learning theories, such as behaviourism, cognitivism and constructivism, emphasise that knowledge level is an essential factor when determining an

instructional strategy (Ertmer and Newby 1993). An individual's level of knowledge is determined by their ability to recall, understand or apply specific information relevant to a particular topic (Brusilovsky and Millán 2007). Therefore, accounting for both dyslexia type and knowledge level when delivering learning material can be important to the educational experience.

Modern e-learning systems are characterised by adaptive learning as a fundamental technique which is increasing in popularity (Rodrigues et al. 2019). However, adaptation is rare in e-learning systems for dyslexia, especially where it considers both dyslexia type and knowledge level. Only limited studies have been conducted in this area, primarily with weaknesses due to issues with research design and a lack of empirical evaluation (Alsobhi et al. 2015; Benmarrakchi et al. 2017c; Alsobhi and Alyoubi 2019). Previous research has mainly focused on a single-source of learner characteristics, such as learning style as described in (Benmarrakchi et al. 2017c; Alghabban et al. 2017) and dyslexia type in (Alsobhi et al. 2015; Benmarrakchi et al. 2017c; Alghabban and Hendley 2020a,b). However, they rarely consider the benefits of multiple characteristics. Some previous research has pointed out the significance of combining different aspects of learners with dyslexia in order to improve the learning process (Benmarrakchi et al. 2017b; Alsobhi and Alyoubi 2020). We argue that more empirical research should be conducted on the effects of adaptation based on both dyslexia type and knowledge level.

This paper aims to explore and investigate the impact of adaptation based on the dyslexia type and reading skill level of learners with dyslexia. It assesses the effect on the learning effectiveness and learner satisfaction. Since the effects of combining these two characteristics are still unknown, an empirical evaluation in terms of learning gain and learner satisfaction was conducted using a carefully designed and well-controlled experiment. The aim of the system built is to support this study – rather than to explore the technical aspects.

In this research, we refer to skill level instead of knowledge level because learning is a multi-dimensional process involving acquiring generic knowledge initially and then, through practice, turning it into usable skills. Learners acquire declarative knowledge and by practicing, they transfer it into specific procedural skills.

This paper is structured as follows: Section two presents a background covering dyslexia and some existing adaptive e-learning systems. Section three presents the current study, including the research questions, hypotheses, measurements, the proposed e-learning system, the experimental procedure and participants. Section four presents the study's results. The fifth section discusses the results. Finally, the last part presents some conclusions and suggests some future work.

2. BACKGROUND

2.1. Dyslexia

Dyslexia is one of the common childhood learning disabilities, making up 80 per cent of the population with learning disabilities (Lerner 1989). According to the main International Classification of Diseases, ICD-10, dyslexia is 'a specific and significant impairment in the development of reading skills, which is not solely accounted for by mental age, visual acuity problems, or inadequate schooling' (p. 245) (World Health Organization 1992). It may adversely affect various skills such as reading recognition, comprehension and performance of tasks requiring oral reading (World Health Organization 1992).

Reading and phonological problems of dyslexia depend on the orthography of the language, either transparent or non-transparent (Elbeheri et al. 2006). In transparent languages, such as Turkish and Spanish, readers have fewer reading difficulties than in non-transparent languages, such as French and English. However, in languages with both orthographies, like Hebrew and Arabic, reading problems vary based on the type of orthography used. For example, in Arabic, there are orthographies with explicit short vowels and other orthographies which omit short vowels (Beland and Mimouni 2001). The severity of reading problems is influenced by the language's orthography and linguistic structure. Hence, whilst dyslexia is universal, the manifestation of its effects are language-dependent (Verhoeven et al. 2019).

This research targets dyslexia in Arabic. Arabic is the official language of 22 countries and is spoken by over 230 million people (Elbeheri et al. 2006). Cursive Arabic style is written from right to left (Elbeheri and Everatt 2007). It has 28 letters, three of which are long vowels (alef (/a:/), yaa (/i:/) and waw (/u:/)) and the rest are consonants. Based on the letter's position within a word, various letter forms are used. Also, some letters have the same shapes, but they differ in the number and position of dots. Additionally, diacritical marks are used to identify three short vowels (fat-ha (/a/), kasra (/i/) and damma (/u/)). Most previous studies have focused on the complexity of this language rather than improving the learning experience of learners with dyslexia by addressing their needs. There is a significant rate of dyslexia in Arabic (Benmarrakchi et al. 2017a).

2.2. Dyslexia Type

Helmer Myklebust was the first researcher to propose classifying dyslexia into different types (Friedmann and Coltheart 2016). To provide better support and understanding of dyslexia, several proposals have been suggested to classify dyslexia based on symptoms (Ingram's classification) (Alsobhi et al. 2014) and the dual-route model for reading (Friedmann and Coltheart 2016). The dual-route model describes the components of the reading process that every reader must master, as explained in (Friedmann and Coltheart 2016). Any deficit in these components causes a reading impairment and thus a type of dyslexia, leading to 10 different types of dyslexia. Some of these types have been reported in diverse languages, such as Hebrew, Arabic and English. This theoretical model is widely applicable and has proven effective and accurate (Annett 1996). Therefore, this is the approach adopted in this research.

In Arabic, seven types of dyslexia have been reported based on the dual-route model. Among these types, Letter Position Dyslexia (LPD) and Vowel Dyslexia (VD) are the most common and frequent in Arabic (Friedmann and Haddad-Hanna 2014). Therefore, this research targets these dyslexia types. People with LPD experience difficulty encoding the position of letters within a word. It is characterised by migrating middle letters within a word while keeping the first and last letters in their original positions. For example, 'cloud' might be interpreted as 'could'. On the other hand, individuals with VD transpose, omit, add or substitute vowel letters. For example, the word 'bit' can be read as 'boat' or even 'but' (Friedmann and Haddad-Hanna 2014).

2.3. Adaptivity in E-Learning Systems for Dyslexia

Adaptive e-learning systems can adapt gamification elements, user interface elements, learning content or presentation according to the characteristics of the learners with dyslexia. The literature has proposed several adaptive e-learning systems. For example, Alghabban et al. (2017) have developed a cloud-based m-learning system with customisable interfaces and multiple types of input and output (text, image, audio) based on the learners' learning styles. This system was evaluated using pre- and post-tests in primary schools with Arabic dyslexia and showed an increase in the learners' reading skills after three months. Further, another study that considers dyslexia learning styles was conducted by Benmarrakchi et al. (2017c). An adaptive mobile learning game based on an analysis of learning style differences has been introduced to enhance and support learning for learners in reading, comprehension, writing, concentration, short-term memory and Arabic orthography.

Additionally, some studies consider dyslexia type as an adaptive parameter when designing e-learning courses. For example, Alsobhi et al. (2015) presented a Dyslexia Adaptive E-Learning (DAEL) framework that adapts itself based on dyslexia type to enhance the educational process. The framework has four dimensions: presentation, hypermediality, accessibility and acceptability and user experience. Additionally, a study by Alghabban and Hendley (2020b) examined how personalising learning materials based on dyslexia type can affect Arabic children's satisfaction. As part of the development of the system, a controlled experimental study evaluated children's satisfaction. When learners are presented with learning content aligned with their dyslexia type, they become more engaged in their learning.

Other studies consider more than one characteristic of dyslexia in e-learning systems. For example, Alsobhi and Alyoubi (2020) have addressed whether incorporating dyslexia type and learning styles of learners with dyslexia will be beneficial. They referred to Felder-Silverman learning styles and Ingram classifications of dyslexia. Research also shows that visual preference is strongly correlated with dyslexia reading difficulty. Further, Benmarrakchi et al. (2017b) have developed an adaptive e-learning system for Arabic that can adapt content to each learner's learning style, cognitive abilities, prior knowledge and experience. Learning is intended to be more accessible for learners through the proposed system. Moreover, a dyslexia adaptive e-learning management system was developed to personalise curriculum structure, presentation and navigation based on learners' learning styles, knowledge levels and types of dyslexia (Alsobhi and Alyoubi 2019).

In addition to the learning style and knowledge level as adaptive parameters, El Fazazi et al. (2021) also considered the types of disabilities. As a result, they proposed a multi-agent adaptive e-learning architecture considering three characteristics of English learners: knowledge level, learning style based on the Felder-Silverman learning style model and disabilities (dyslexia, hearing impairments and visual impairments). The system recommends a learning path and learning objects according to a learner's profile. In addition, for dyslexia in the Malay language, Abdul Hamid et al. (2017) have developed an adaptive e-learning system based on learners' behaviour and difficulties. In order to achieve this, the researchers conducted various semi-structured interviews to collect the required information about learners and materials in primary schools.

Reviewing the literature, the effect of adapting based on learner's knowledge level and dyslexia type has rarely been the subject of research for dyslexia. Some studies have examined the significance of

adapting based on a learner's knowledge level (Benmarrakchi et al. 2017b; El Fazazi et al. 2021), dyslexia type (Alsobhi et al. 2015; Alsobhi and Alyoubi 2020), or both (Alsobhi and Alyoubi 2019). However, these systems are not conclusive at this stage due to the lack of well-designed, controlled experimental evaluation, or they have not been implemented to reflect the impact of adaptation according to these two characteristics, leading to difficulty in evaluating the proposed system's effectiveness. This is true for other research in different languages, such as English, Malay and Arabic. Rather than simply introducing new and novel systems, a carefully designed and controlled evaluation is more crucial (Gauch et al. 2007). In addition, these proposed systems are not presented with a design methodology, which makes it challenging to evaluate their effectiveness (Benmarrakchi et al. 2017c; Alghabban et al. 2017).
Overall, there is very little research that is based on theories of dyslexia to generate adaptive learning. Even when they have done so, the evaluation of its effectiveness is very limited.

3. THE PRESENT STUDY

According to the previous literature review, the impact of adaptation based on both dyslexia type and knowledge level characteristics is still under-investigated in the context of different languages, despite the significance of these two characteristics in learning (Ertmer and Newby 1993; Friedmann and Haddad-Hanna 2014). Therefore, this research aims to investigate the impact of combining two characteristics of learners, dyslexia type and reading skill level, among Arabic children with dyslexia on their learning improvement and satisfaction.

3.1. Study Question and Hypotheses

This research addressed the following question: **Does adapting e-learning material based on the dyslexia type and reading skill level of learners with dyslexia improve the learning experience compared to non-adaptive material, and does it achieve a high level of learner satisfaction?**.
Five hypotheses were formulated in this research and each one presents a dependent variable:
H1: Matching learning material to dyslexia type and reading skill level of learners achieves significantly better **short-term learning gain for seen words** compared to non-matched material.
H2: Matching learning material to dyslexia type and reading skill level of learners achieves significantly better **long-term learning gain for seen words** compared to non-matched material.
H3: Matching learning material to dyslexia type and reading skill level of learners achieves significantly better **short-term learning gain for unseen words** compared to non-matched material.
H4: Matching learning material to dyslexia type and reading skill level of learners achieves significantly better **long-term learning gain for unseen words** compared to non-matched material.
H5: Matching learning material to dyslexia type and reading skill level of learners achieves significantly better **learner satisfaction** compared to non-matched material.

3.2. Measurements and Data Collection Tools

Data was collected using several tools: diagnostic tests, reading accuracy tests (pre-, post- and follow-up tests) and a satisfaction tool.
Dyslexia type diagnostic tests determined the dyslexia type. These tests include 20 sensitive words to detect LPD and VD. The reading skill level diagnostic tests determined the reading skill level of the learner. Three Reading Skills (RS) were targeted in this research, reading letters with short vowels (RS1), reading words with Sakin letter(s) (RS2) and reading words with short vowels and Sakin letter(s) (RS3). Three reading skill diagnostic tests assessed each skill. The RS1 test consists of 48 three-letters words with short vowels to assess the learner's ability to correctly spell letters in these words. The RS2 test included 10 vowelised words with Sakin letter(s) within words of two and three letters. The RS3 test consists of 10 vowelised words of three to five letters with a combination of short vowels and Sakin letters used to assess the learners' skill level. All diagnostic tests for dyslexia type and reading skill level were based on reliable and standardised tests approved by the Ministry of Education in the Kingdom of Saudi Arabia (KSA) for special needs students (Bukhari et al. 2016). For each test, each participant was asked to read aloud each word individually to determine whether they could read it correctly or not.
Pre- and post-tests assessed the amount of learning that learners gain from the course (Pickering 2017) – learning gain. The experiment measured two types of learning gain: seen words and unseen words learning gains. By seen words we mean words included in the material provided by the e-learning system, while unseen words refer to words not included in the e-learning system's material. The unseen words learning gain was measured to assess whether the content learned can be generalised to new words (Nist and Joseph 2008). The tests contain 20 words (10 words to assess learning gain of seen words and another 10 words to assess learning gain of unseen words) and have been validated by special education experts. Each learner reads aloud the words to establish their level of reading accuracy.

For each type of learning gain, the experiment evaluated both short-term and long-term gains. The short-term learning gain was assessed immediately after the completion of the experiment by administering the post-test to determine what participants had learned. It reflects the immediate results of matching learning materials to learners' characteristics on improving their reading accuracy. Short-term learning gain is calculated by subtracting the pre-test score from the post-test score (Pickering 2017). The long-term learning gain was assessed to determine if learning persists over time (Nist and Joseph 2008) by asking participants to complete a follow-up test after two weeks had passed. It indicates the sustained learning of participants over time and any delays in their learning gains. Long-term learning gain is calculated by subtracting the pre-test score from the follow-up test score. In this experiment, pre-, post- and follow-up tests for measuring seen and unseen words learning gains were the same (had the same content) to allow an accurate comparison of reading abilities (Bonacina et al. 2015).
Learner satisfaction is a critical indicator of the quality and effectiveness of the system (Kuo et al. 2013). The E-Learner Satisfaction (ELS) questionnaire measured participants' satisfaction (Wang 2003). It is a validated and reliable tool, consisting of 17 items with 7-point Likert scales ranging from 'strongly disagree' to 'strongly agree'. The ELS assesses overall satisfaction and satisfaction with various components, such as the system interface, system personalisation and learning content. A version of ELS adapted to a 5-point scale using the Smileyometer was used as it is easy to understand by children and matches their cognitive abilities (Alghabban and Hendley 2020b). The Smileyometer uses pictorial representations with these scales (awful, not very good, good, really good, brilliant) (Read et al. 2002).
Other metrics can be affected by adaptation, such as word comprehension and perceived level of usability. These metrics were measured in this research, but they are not included here due to the paper limits.

3.3. DTRST System

The Dyslexia Type and Reading Skill Training system (DTRST) was designed to support this research. It is a dynamic, web-based e-learning system that matches the learning material to both dyslexia type and reading skill levels. This system trains learners by providing several word recognition activities, divided into six training sessions, each with 20 activities. The difficulty level of activities increases gradually. The word level is chosen because one of the common difficulties in the literature about Arabic dyslexia is word recognition (Al-Wabil et al. 2006) and it is a strong predictor of reading fluency (Burke et al. 2009). Learners have already acquired basic knowledge in reading and by practising, they can take these skills and apply them subconsciously in the most efficient manner rather than by using conscious reasoning.
There are two versions of DTRST to support the experimental conditions: a control group and an experimental group. The experimental group interacts with a matched version of DTRST that matches the learning material of activities to LPD, VD, RS1, RS2, or RS3, while the control group interacts with the non-matched version of DTRST that provides the standard learning material (a combination of all dyslexia type and reading skills learning material). The system layout and interface were identical for both groups, but the key difference is the provided learning material.
Figure 1 shows an example of a training activity. Designing the DTRST's interface follows the guidelines for web design accessibility for Arabic content in terms of font size and type and background and text colour (Al-Wabil et al. 2006). A central image appears on the screen with three choices; each one shows different words. The learner clicks on the image to hear the target word and then chooses one of the three answers (one correct and two incorrect). It is possible to re-play the target word as many times as the learner wishes by clicking the image. Also, the image can be used as a hint. Positive feedback is given to the learner if they choose the correct word. Alternatively, corrective feedback is given. Training activity numbers are displayed at the top of the screen to indicate training progress. An inspirational message is displayed with the learner's score at the end of each session.

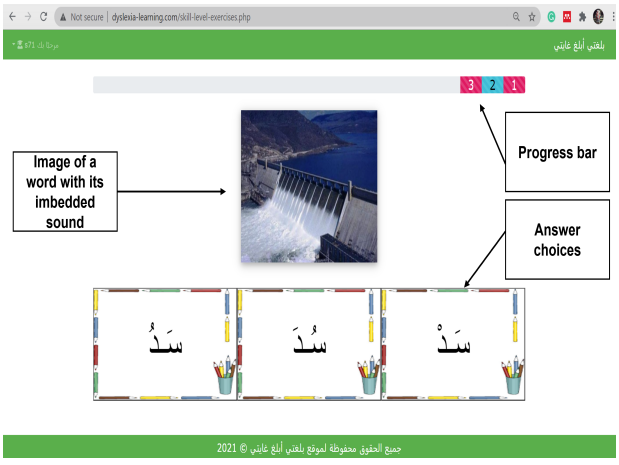

Figure 1: *An example of a training activity displayed by the DTRST interface.*

The content of the learning material was drawn from the primary school curriculum and has been evaluated by special education experts. The material for LPD includes short vowels and Sakin letter(s) progressing from simple words (two-letters words

with only fat-ha and Sakin letters) to advanced ones (four-letter words with a mix of short vowels and Sakin letter(s)). A Sakin letter is a letter with a small circle on top of it, which is a letter that does not contain a vowel. The material for VD includes short and long vowels progressing from simple words (three-letters words with only fat-ha and alef) to advanced ones (for example, four or five-letters words with a mix of all short and long vowels). The learning material for RS1 includes reading letters with short vowels, progressing from the simple short vowel (fat-ha) to advanced ones (damma). Learning materials for RS2 include reading words with Sakin letters that gradually progress from simple words (two-letters words with one Sakin letter) to advanced words (three- and four-letters words with two Sakin letters). As part of RS3, the material includes words with short vowels that progress from simple words (words with three letters and only fat-ha) to more advanced ones (words with three- and four-letters and a mix of short vowels and Sakin letters).

3.4. Experimental Procedure

This study was ethically approved by the institution. Parents/guardians and schools had to consent before learners could participate in the experiment. A consent form outlines the purpose and type of data that will be collected and what participants can expect from the experiment.

To answer and evaluate the research question, a between-subjects experimental design approach was used in which each participant experienced only one condition. This approach eliminated the possibility of carryover from one condition to another. The experiment ran remotely via Microsoft Teams due to schools' closures (COVID-19). Participants were introduced to the experiment's objectives before beginning. Then, their demographic information (age, grade) was collected and the dyslexia type and reading skill level were determined using the diagnostic tests. The study excluded participants with other or multiple types of dyslexia and the targeted reading skills. Afterwards, the pre-tests of seen and unseen words were administered to all participants to determine their initial reading accuracy. Then, participants were distributed into two independent groups, experimental and control groups, balanced by age, grade, prior reading accuracy (pre-tests results of seen and unseen words), dyslexia type and reading skill level.

The study was first introduced by the experimenter, who was present at each session with each participant individually to make an observational record. There were six sessions of approximately 30 min, two sessions per week over three weeks. The experiment was double-blind in that neither the participant nor the experimenter knew what condition was being used.

After finishing the experiment, the post-tests of seen and unseen words were administered immediately, as was the ELS tool. After two weeks, the follow-up tests of seen and unseen words were undertaken.

3.5. Participants

Forty-seven participants with a mean age of 10.09 (SD = 1.3) took part in the experiment. They were selected from primary schools in KSA. They were all Arabic females and were familiar with electronic devices. KSA institutions separate males from females, so males were not enrolled. However, this had the benefit of reducing variance among participants. Figure 2 presents the participants' characteristics.

4. RESULTS

The participants were randomly assigned either to the control group (n = 24, mean age = 10.04 years, SD = 1.27) or the experimental group (n = 23, mean age = 10.13 years, SD = 1.36). There is no statistical difference between the means of both groups in age (p = 0.878 $>$ 0.05), the prior level of reading accuracy, measured by the pre-test of seen words (p = 0.754 $>$ 0.05) and the pre-test of unseen words (p = 0.698 $>$ 0.05). All of the participants completed the experiment. IBM SPSS Statistics software was used to analyse the data collected.

4.1. Learning Gain of Seen Words

The two hypotheses (H1, H2) about short- and long-term learning gain of seen words were tested. As shown in Table 1, a post-test, follow-up test, short- and long-term learning gains of the experimental group were higher than those of the control group. The results indicate that matching learning material to both dyslexia type and reading skill level in DTRST leads to a positive effect. As the short-term learning gain score distributions were not normally distributed (Shapiro-Wilk's test $p < 0.05$), an independent sample Mann-Whitney U test was used to determine if there were differences between the groups. The results indicate that the short-term learning gain scores for the experimental group (Mean Rank = 33.74) was statistically significantly higher than the control group (Mean Rank = 14.67), U = 500, Z = 4.851, p = 0.000001. There was also a large effect size (r = 0.71). So, the first hypothesis is confirmed and DTRST's matching of learning material to dyslexia type and reading skill level results in significantly greater short-term learning gain of seen words than without matching.

The significance of the long-term learning gain of seen words was also examined. As long-term learning gain scores for each group were normally distributed, as assessed by Shapiro-Wilk's test (p

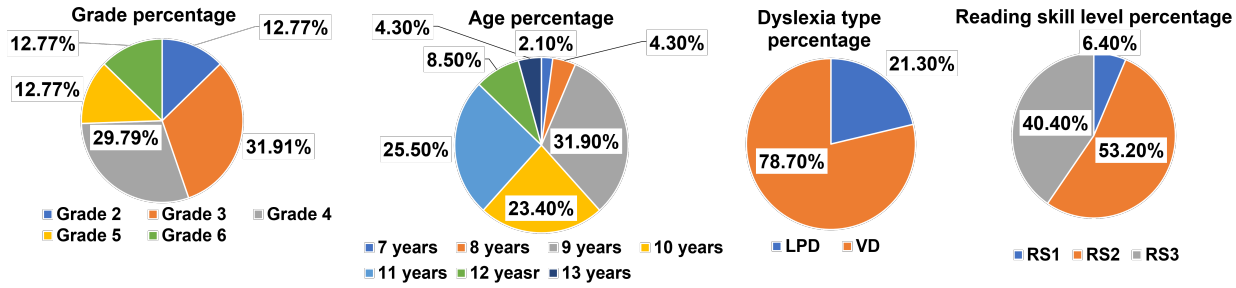

Figure 2: *Participants' characteristics.*

Table 1: *Pre-test, post-test, follow-up test, short- and long-term seen words learning gain results.*

Group	N	Pre-test		Post-test		Follow-up test		Short-term learning gain		Long-term learning gain	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Control	24	4.54	2.11	5.83	1.74	5.88	1.75	1.29	1.16	1.33	2.01
Experimental	23	4.78	2.15	8.39	1.61	8.74	1.25	3.61	1.23	3.96	1.64

$>$ 0.05) and there was homogeneity of variance for learning gain scores for both groups as assessed by Levene's test for the equality of variances (F = 0.574, p = 0.452), an independent sample t-test was run using an alpha level of 0.05 to determine if there were differences in long-term learning gain scores between two groups. Examination of the means of long-term learning gain indicated that the experimental group had significantly higher long-term learning gain than the control group, t(45) = -4.89, p = 0.000013. In addition, the effect size of the finding was very large (Cohen's d = 1.43). Therefore, the second hypothesis is confirmed and matching learning material to dyslexia type and reading skill level in DTRST yields significantly better long-term learning gain of seen words than without matching.

4.2. Learning Gain of Unseen Words

H3 and H4 (which are about short- and long-term learning gain of unseen words) were tested. According to Table 2, the experimental group achieved a greater post-test, follow-up test, short- and long-term learning gains than the control group. Results indicate that matching learning material to dyslexia type and reading skill level in DTRST generally had a positive effect. As the short-term learning gain score distributions deviated from the normal distribution (Shapiro-Wilk's test $p < 0.05$), an independent sample Mann-Whitney U test was used to determine if there were significant differences in short-term learning gain scores between the two groups. The short-term learning gain scores for the experimental group (Mean Rank = 34.13) were significantly higher than the control group (Mean Rank = 14.29), U = 509, Z = 5.056, $p < 0.001$. Also, the effect size of the finding was large (r = 0.74). This result confirms the third hypothesis, so it can be concluded that learning materials that are matched to the dyslexia type and reading skill level in DTRST significantly increase short-term learning gains of unseen words compared to non-matched ones.

A test also determined the significance of long-term learning gains of unseen words. As the long-term learning gain score distributions in the control group deviated from the normal distribution (Shapiro-Wilk's test $p < 0.05$), an independent sample Mann-Whitney U test was used to determine if there were differences in long-term learning gain scores between the two groups. The results indicate that the long-term learning gain scores for the experimental group (Mean Rank = 34.33) were statistically significantly higher than the control group (Mean Rank = 14.1), U = 513.5, Z = 5.115, $p < 0.001$. In addition, the effect size of the finding was large (r = 0.75). These results support the fourth hypothesis. Thus, matching learning material to dyslexia type and reading skill level in DTRST yields significantly better long-term learning gain of unseen words than without matching.

4.3. Learners' Satisfaction

According to the analysis of the learners' satisfaction, as shown in Figure 3, the experimental group had higher mean learner satisfaction scores in terms of the learning content, the system interface and the system personalisation than the control group. The mean satisfaction score for the experimental group (Mean = 4.7, SD = 0.33) was greater than the control group (Mean = 4.1, SD = 0.45), indicating that matching learning materials to learners' dyslexia type and reading skill level in DTRST improved learners' satisfaction.

Table 2: *Pre-test, post-test, follow-up test, short- and long-term unseen words learning gain results.*

Group	N	Pre-test		Post-test		Follow-up test		Short-term learning gain		Long-term learning gain	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Control	24	2.96	2.05	3.5	2.02	3.58	2.15	0.54	1.02	0.63	1.09
Experimental	23	3.17	2.17	6.13	1.77	6.78	1.35	2.96	1.39	3.61	1.64

There was a statistically significant difference between the overall satisfaction in the two conditions (Independent sample Mann-Whitney U test (U = 484, Z = 4.441, p = 0.000009)). In addition, the effect size of the finding was large (r = 0.65). Therefore, the fifth hypothesis is confirmed and matching learning material to dyslexia type and reading skill level in DTRST yields significantly better learners' satisfaction than without matching.

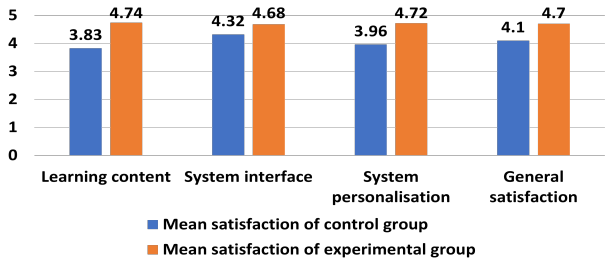

Figure 3: *Satisfaction scores of participants.*

5. DISCUSSION

The conducted study in this research varies in comparison to earlier studies on dyslexia in that it investigates two distinct characteristics of learners with dyslexia: dyslexia type and reading skill level. Earlier research was limited by their small sample sizes and lack of formal study design and evaluation (Alsobhi et al. 2015; Benmarrakchi et al. 2017b; Alsobhi and Alyoubi 2019, 2020; El Fazazi et al. 2021). A unique feature of this study is that it reports the results of a carefully designed and controlled experiment with a reasonable number of participants.

This study contributes to current research on dyslexia and adaptive e-learning systems. The study findings are not limited to a short-term learning gain evaluation. Follow-up tests also assessed the sustaining and persistence of knowledge. Based on our experience, it is rare to find studies examining both immediate effects of adaptation on dyslexia learning gains and whether they are persistent over time. In contrast, the current study is distinctive in assessing reading performance on new material. Learners retained and generalised the reading of new words, which were not taught in the system when adapting material to their needs.

This study also found that this adaptation, based on the combination of dyslexia type and reading skill levels, significantly improved learning gains for both seen and unseen words and that this effect persists, rather than just being a short-term effect. This suggests that the learning leads to an improvement in generalisation as well as in the practice of individual words.

This result is consistent with the previous study (Daly III et al. 1996) that argued that materials that better match learners' skill levels will result in more accurate performance and, therefore, a greater likelihood of generalisation of passage reading. As in classroom practice, once the learner's reading level is determined, the teacher decides which reading materials are appropriate for each learner, allowing for more successful learning (Dolgin 1975). Also, these results are in line with previous research that matches learning to dyslexia type (Alghabban and Hendley 2020a).

Finally, this study showed that learners were more satisfied and engaged when the system adapted learning material to their dyslexia type and reading skill level. The results are consistent with previous studies (Alghabban et al. 2017; Alghabban and Hendley 2020b). Both conditions had identical interfaces, but all satisfaction components, including interface, learning content and system personalisation, in the experimental condition received a higher rating. Though learners may not be conscious of this match, they are subconsciously aware of it, which is reflected in their assessment of aspects of the system that do not change between conditions.

6. CONCLUSION

This research evaluated the impact of combining two essential characteristics of learners with dyslexia in adaptive e-learning systems: dyslexia type and reading skill level (Ertmer and Newby 1993; Friedmann and Coltheart 2016), which is still a significant gap in existing research for dyslexia in different languages, including Arabic. Moreover, this research addressed the lack of well-designed and controlled experimental studies in previous research (Alsobhi et al. 2015; Benmarrakchi et al. 2017b; Alsobhi and Alyoubi 2019, 2020; El Fazazi et al. 2021). An empirical study was conducted with 47 Arabic learners with dyslexia to evaluate the approach. The results indicate that adapting based

on dyslexia type and reading skill levels enhances both short-term and long-term learning gains of both seen and new materials and also learner satisfaction. Other metrics were assessed in this study, such as word comprehension and perceived level of usability. These findings were also showed a significant benefit when adapting materials to the two characteristics. However, these findings were not reported due to the paper size limit.

This paper contributes to recent research on adaptive e-learning systems and dyslexia by highlighting the significance of adaptation based upon dyslexia type and reading skill level. Although this study focused on females, we believe the results can be generalised to males and different age groups. Further research will be needed to confirm this. Also, future studies should include more extensive learning resources with more participants. This study may also offer lessons for other languages. Additionally, the same methodology can be used for other domains of application. It would be valuable to examine adaptation based on other factors (such as personality or learning style) due to dyslexia comorbidities.

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