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Understanding the Impact on Learners' Reading Performance and Behaviour of Matching E-Learning Material to Dyslexia Type and Reading Skill Level*

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Abstract. Dyslexia is a universal reading difficulty where each individual with dyslexia can have a different combination of underlying reading difficulties. For instance, errors in letter identification or omissions or transpositions within or between words. Nowadays, adaptive e-learning and gamification have become more common. Different learner characteristics have been used when adapting e-learning systems, such as the user's learning style or knowledge level. However, little attention has been directed towards understanding the benefits of using dyslexia type or reading skill level when adapting systems for learners with dyslexia. This, despite dyslexia type and reading skill level being significant factors in their education and learning. This paper reports on research which aims to improve this understanding through empirical studies designed to evaluate the benefits of adaptation with native Arabic speaking children with dyslexia. A mixed-methods approach was used. In the first experiment the focus is on a qualitative understanding of the effects of adaptation based on dyslexia type. The second experiment provides a quantitative analysis of the effects of adaptation based upon the reading skill level of learners with dyslexia. Findings revealed that the majority of learners are motivated when adapting learning material to dyslexia type. Analysis of the results indicated that adapting based on reading skill level does achieve improved learning gain and lead to greater learner satisfaction compared to a non-adaptive version. Implications of these experiments are discussed.

Keywords: Dyslexia type · Skill level · Arabic · Adaptation · E-Learning

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1 Introduction

Reading is one of the most important basic linguistic skills [29]. The majority of readers are able to understand written text automatically and easily. However, many readers face difficulties and have to apply conscious effort when reading. This can, in turn, lead to social and educational exclusion [29]. These readers are known as people with dyslexia.

Dyslexia has been defined by the main international classification, ICD-10 [44] as "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". Typical symptoms include inaccurate and/or slow word recognition, comprehension, misspelling and poor decoding abilities [44].

E-learning can support the development of learners' knowledge and skills without the constraints of time and place [16]. However, traditional e-learning systems have several drawbacks compared to real-life teaching [19]: they provide the same learning experience to all learners. This decreases the effectiveness of the learning and can lead learners to become dissatisfied and demotivated [37].

Adaptive e-learning systems and gamification aim to improve learners' experience by making the learning process more effective, and increasing their satisfaction and engagement [31, 34]. These systems can adapt the learning content and presentation based upon different characteristics of learners [15]. For learners with dyslexia, dyslexia type and reading skill level are significant factors in their education [20, 22]. The dual-route model for single word reading predicts different types of dyslexia, each resulting from different underlying causes [21]. The reading skill level of a learner is also a significant characteristic that should be considered [27]. There is, therefore, a strong argument that such an e-learning environment should apply different teaching approaches based on these two characteristics, rather than treating all learners the same.

This research aims to investigate the impact of adapting learning material based on dyslexia type and reading skill level in a computer-based training system for Arabic. There is very limited research that explores teaching learners with dyslexia to read Arabic [7], despite it being a widely spoken language [30] with a high rate of dyslexia [11]. A mixed-methods approach, using qualitative and quantitative methods, is used to collect and analyze data. An evaluation, in terms of learning performance and learners satisfaction, is presented.

The remainder of this paper is organized as follows. Section two presents some important background upon which the studies are built. Sections three & four present the experimental procedures in detail, followed by the discussion in Section five. Finally, Section six draws some conclusions and points to future work.

2 Background

This section covers the theoretical foundation behind this research: features of Arabic orthography relevant to dyslexia, dyslexia types in Arabic based on the dual-route model for single word reading, adaptation in e-learning and further related work.

2.1 Dyslexia in Arabic

Dyslexia is sensitive to language. The differences in language orthography and structure have a large impact on the difficulties that the readers face. Unfortunately, there are few studies that explore dyslexia in Arabic. This research targets training young, native Arabic speaking learners with dyslexia.

Arabic is the fifth most spoken language. Over 200 million individuals speak Arabic as their first language. It is also used as a second language by millions of Muslims [30]. The Arabic orthography is different from that of English. Therefore, the manifestation of dyslexia [6] is also different [18]. For instance:

- The cursive nature of the Arabic language (where the letters are joined to form a word or sub-word).
- The use of dots to distinguish between different letters.
- Different letter forms depending on the position within a word.
- The use of non-vowelized text (a non-transparent orthography) [18].

Types of Dyslexia in Arabic Helmer Myklebust, was the first person to suggest classifying developmental dyslexia into different types [21]. There have been several proposals for classifying dyslexia in order to develop a better understanding and thus to provide better support [8, 21]. Dyslexia has been classified based on 'symptoms' (Ingram's classification) [8] and also by using the dual-route model for single word reading [21]. Here, Friedmann and Coltheart [21] suggested using that model in order to predict the different 'symptoms' of different types of dyslexia. The dual-route model has proved effective and is widely used [9]. Consequently, this is the approach adopted in this research.

In order to understand the types of dyslexia based on the dual-route model for single word reading, understanding the process is essential (see Fig. 1).

The reading process can be summarized in the following stages:

- The **orthographic-visual analysis system** analyzes the target word to identify its letters, encode each letter's position within the word and bind these letters to that word.
- The result from the previous stage is stored in the **orthographic input buffer** that decomposes the word to its stem. For instance, decomposing the word "birds" into "bird".
- The lexical-phonological route is used for reading familiar words (known written words stored in the reader's lexicon) quickly and accurately. This is achieved by passing the word to the **orthographic input lexicon**:
  - The **phonological output lexicon** will write to the **phonemic output buffer**.
  - The corresponding entry in the **conceptual-semantic system** is activated to access the word's meaning.

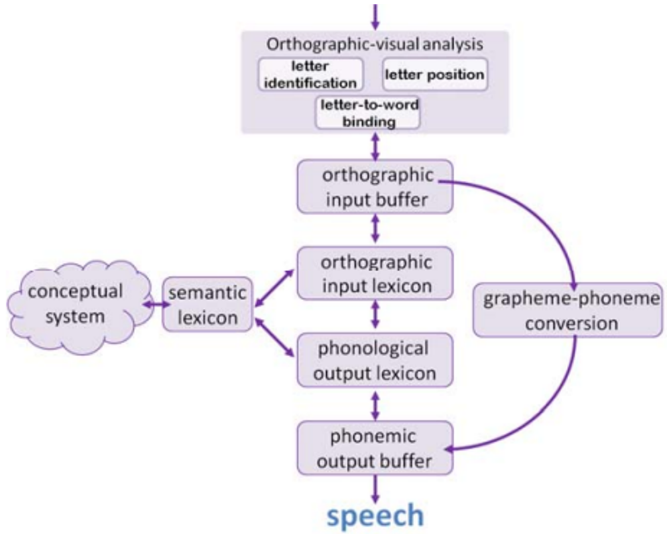

Fig. 1. Dual-route model for a single word reading [21].

– The sub-lexical-phonological route is used for reading unfamiliar words. This is accomplished by passing the written word to the **grapheme-to-phoneme conversion** component. It analyzes the letters into either letters or groups of letters (graphemes) that form a single phoneme. Finally, this information is passed to the **phonemic output buffer**.

As seen in the previous stages, each component of the dual-route model is essential and performs an important task in the reading process. A deficit in any component will cause a reading impairment and thus a type of dyslexia.

Dyslexia in Arabic is classified into seven types based on the deficit in the dual-route model [22]. This research focuses on only two frequent types; **Letter Position Dyslexia (LPD)** and **Vowel letter Dyslexia (VD)** [22].

LPD arises from an inability to encode the order of the letters within the word due to a reading deficit in the orthographic-visual analyser stage, specifically the function that is responsible for encoding the relative position of letters within the word [21, 22]. They migrate letters within words especially the middle ones [21, 22].

On the other hand, VD suffers from omitting, transposing, substituting and adding vowel letters (such as reading the word "bit" as "but" or even "boat") due to a specific deficit in the sub-lexical route which impairs the way the vowels are processed [21, 22]. Such errors appear only with the vowel letters during reading and not with vowel phonemes during speech production [21].

In the Arabic orthography, three aspects should be considered [22]:

– Each vowel letter identifies a single long vowel.

– There is a difference between long and short vowels. Long vowels are encoded orthographically, while short ones are usually eliminated from written words.
– A vowel letter has different forms depending on its position.

Friedmann and Haddad-Hanna [22] found that VD occurs more frequently, with typical errors including: vowel additions, migrations, omissions, and substitutions. Vowel addition is indicated by the elongation of a short vowel, while vowel omission is indicated by shortening a long vowel.

2.2 Adaptation in the E-learning Domain

The emergence of e-learning has enabled the wider learner community to have access to educational content. However, such wider access has raised concerns with respect to the delivery of appropriate learning experience to different learners, since most e-learning systems do not adapt material to meet the needs of the individual learner [19]. Research aims to find ways in which the specific needs of a learner can be identified, and material adapted to suit those needs [19].

Another challenging task in e-learning is motivating learners to use such systems in order to enhance their learning gain. Gamification has proved to increase learners motivation, engagement, and to support them through their interaction with material [34].

In the context of e-learning systems, adaptation is defined as a procedure for tailoring the educational environment to these differences [14] with the aim of improving learning outcome [31]. Different learner characteristics can be considered such as knowledge level [32] and learning styles [35]. Learners with dyslexia, like everyone, are different in their needs, preferences, and their skill level. These parameters must also be considered in adaptive e-learning systems. Therefore, this research focuses on types of dyslexia and their reading skill level.

Skill Level According to Self [38], "a student model is what enables a system to care about a student". Different learners' data and characteristics can be represented in a learner model as sources for providing adaptation [19]. These characteristics can be classified into affective (motivation and emotions), cognitive (knowledge level, skill level), and conative (learning style and goals) [39]. Data can be collected implicitly, explicitly or a combination of both. Implicit techniques involve feedback generated from the system that monitors user activity like page scrolling, time spent on a page and page visits [23]. Explicit techniques involve feedback generated from the user like tests and questionnaires [23].

One of the most common learner modelling techniques in adaptive e-learning systems is the overlay model [40]. The overlay model is often used to represent the learner's knowledge [16]. The key idea of the overlay model is that the learner model is a subset of an idealised domain model based on the assumption that a learner may have correct but incomplete knowledge of the domain [16]. The domain is decomposed into a set of elements and the overlay model is a set of masteries over those elements. The overlay model, in its simplest form, assigns a Boolean value (yes or no) to each element in the domain, indicating whether a learner knows or does not know that element. It can also use qualitative values (poor, average, good) or a quantitative measure (the probability that the learner knows the concept) [15]. Although the overlay model is used extensively due to its representation of learner knowledge for each concept independently, one drawback is that it does not represent incorrect knowledge or misconceptions. In addition, it cannot represent other characteristics such as learners' behaviour, personality and preferences [16]. For this reason, many adaptive e-learning systems use a combination of other learner modelling approaches with the overlay model.

Among learner characteristics, learners' knowledge level is recognized as a fundamental factor [20], when presenting learning materials to the learner [19]. It describes the extent to which a learner understands, applies and recalls specific information related to a particular topic [35]. Learners' knowledge level is one of the most commonly used adaptive parameters. For example, SQL-Tutor [33] and ELM-ART [43] both consider learners' knowledge level in order to adapt learning content. Also, ActiveMath adapts mathematical content to learners' knowledge level, goals and media preferences [32].

In this research, we refer to skill level rather than knowledge level. Knowledge is learning principles of a subject, while skill is the ability to apply that knowledge in a context. According to Sun and Peterson [41], individuals learn generic and declarative knowledge first and then, through practice, turn such knowledge into specific, usable procedural skill. This research targets training young learners in reading skills. The learners already have the basic, formal knowledge and by practising they develop it into specific skills which can be applied subconsciously rather than through conscious reasoning.

2.3 Related Work

Some e-learning systems have been developed to teach Arabic learners with dyslexia. Some of these systems adapt based on learner characteristics while others do not.

In terms of adaptivity, Alghabban et al. [3] investigated how personalizing learning material based on dyslexia type affects children's satisfaction. An adaptive e-learning system was implemented to help children in elementary schools to practice their reading skill. The system was evaluated by a controlled experimental study. The results showed that children with dyslexia were more engaged with their learning experience when matching the learning content to their dyslexia type. However, the learning performance and effectiveness were not considered.

Other research has considered the learning style of learners with dyslexia as one characteristic in adaptive e-learning systems. For example, Benmarrakchi et al. [12] developed a framework for an adaptive m-learning system to support children with dyslexia. The proposed system aimed to enhance the students' fundamental skills such as reading, comprehension, writing, concentration, short-term memory and Arabic orthography. However, the evaluation methodology was not presented, leading to difficulty in understanding its effectiveness. Similar work has been done by Alghabban et al. [2] by developing a cloud-based m-learning tool for learners with dyslexia in primary schools. The proposed tool enabled manual adaptation of the interface and different modalities of input and output based on learning styles of learners with dyslexia. The tool was evaluated using pre- and post-tests and demonstrated an increase in reading skills after three months use. However, again, the design methodology was not presented, which makes it difficult to evaluate the effectiveness.

Overall, there is very little research which draws upon the theoretical understanding of dyslexia and which uses this to derive adaptive learning. Where this has been investigated, the evaluation of its effectiveness is very limited. Therefore, in this research we seek to build upon existing research into the causes and effects of dyslexia and understand whether and how this can be used to derive adaptation of learning to improve the learners' experience.

3 Experiment 1: Dyslexia Type Adaptivity

This experiment aims to understand the impact of adapting learning material based on dyslexia type, on the behaviour of learners with dyslexia. A between-subject experiment was conducted. A mixed-methods approach was used to collect and analyze the data. The quantitative data, in term of learning gain and learner satisfaction scores, is reported in [1].

3.1 Data Collection

Data was gathered by using: a dyslexia type diagnostic test, a pre-reading test and taking notes when observing learners. The dyslexia type diagnostic test was used to determine learner's dyslexia type. It is based on the standardized tests approved by the Ministry of Education in Saudi Arabia. The test was validated by a number of special education experts and refined to produce the final version. The pre-reading test was used to determine the learner's reading skill level.

3.2 DysTypeTrain System

The Dyslexia Type Training system (*DysTypeTrain*) was designed and implemented to support this experiment. It is a dynamic web-based e-learning system. It trains learners with dyslexia via eight different reading activities, each one containing ten training exercises, giving a total of 80 exercises. The difficulty of these activities gradually increases. In each training exercise, a word is pronounced and an image is displayed along with three choices. Each choice displays a different word.

Fig. 2 shows an example of a training exercise. The learner listens to the target word and chooses the correct answer from the three choices. If the learner chooses the correct word then verbal, encouraging, motivational feedback is given [11], and they gain a point. Otherwise, remedial feedback is given. The total point score is presented at the top left corner of the screen. Feedback on training progress is provided as a training exercise number (between 1 and 10) in the top of the screen. The learner can re-play the target word, as many times as they want, by clicking on the audio icon presented in the middle right of the screen and use the image displayed underneath as a hint. Once the activity is completed, a motivational message is displayed. The experience of success was

Fig. 2. A screenshot of one of the DysTypeTrain system training exercises.

a natural reward which was controlled computationally [28]. The learner should achieve 80% through each activity [28] to unlock the next level. Otherwise, they will repeat it [5]. The incorrect words were chosen to target VD difficulties.

The training material was chosen from the primary school curriculum to target VD. It combines short vowels (fat-ha (/a/), kasra (/i/) and dammah (/u/)), and long ones (alef (a), yaa (i), waw (u)), progressing from simple words (i.e. three-letters words with only fat-ha short vowel & alef long vowel) to advanced ones (i.e. five or six-letters words with a mix of all short and long vowels).

3.3 Method

Originally, this experiment targeted VD and LPD due to their frequency [22]. In practice, LPD was not found in the target population and another common reading difficulty was used. This is the difficulty in distinguishing between Short Vowels. It is named by the researcher as Short Vowel Dyslexia (SVD). Therefore, this experiment targeted SVD and VD rather than of LPD and VD.

The experiment took place in Riyadh, Saudi Arabia. Consent was obtained from both schools and learners' parents/guardians. The learners were welcomed and introduced to the objectives of the experiment. Then, their demographic information was collected, and their dyslexia type was determined. The pre-reading test was conducted to assess their initial reading skill level. Learners were divided randomly into two groups, balanced by age, grade, and their prior reading performance. Both the matched (VD) group and mismatched (SVD) group used the same version of the *DysTypeTrain*. The learning material of the website matched the matched group while mismatched the other one.

The experiment took place in person with guidance from the experimenter, in a quiet room, within the learner's school. Nobody was in the room except the learner and the experimenter. The learner sat in front of a desk with a laptop while the experimenter sat next to them observing and solving any technical problems. Learners worked individually. There were eight experimental sessions: two sessions per learner per week. Each session had a duration of approximately 35 minutes and the total duration of the study was one month. At the beginning of the first session, the experimenter explained the *DysTypeTrain* layout. During each session, the experimenter observed the learners and took notes about their interaction with the system and facial expressions. Neither the learner nor the experimenter was aware of the experimental condition to which the learner had been allocated.

3.4 Participants

Originally, 20 female, native Arabic speaking learners, already diagnosed with dyslexia, were recruited from different elementary schools. Due to the Coronavirus pandemic (COVID-19), this number dropped down to 16 who completed the experiment. The learners were aged from 9-14 years (Grades 4 to 6). All had previous experience with electronic devices. The learners were assigned either to the mismatched group (n=8) or the matched group (n=8). Learners had approximately the same prior reading skill level, with no statistically significant difference between the groups. Thirteen of 16 learners completed the experiment in school. The remaining three completed it remotely via Zoom meetings due to the closure of schools (COVID-19).

3.5 Findings

Participant Observations Based on the schools' policy, the sessions were not video recorded. Learner observations were collected using structured notes taken by the experimenter. These data were analyzed using Thematic Content Analysis [13]. In this method, codes (and sub-codes if necessary) are generated from all data collected. Then the codes are synthesized into themes (and sometimes subthemes) and theoretical concepts. These codes should be related to each other within a theme and the themes should also relate to each other and to the entire data set.

When observing the learners during their interaction with the system, several findings were noted in terms of study mode, learners, choices and training activities. In term of **study mode**, 13 learners were able to complete the study in person while the remaining three completed the study remotely using Zoom meetings. In both groups the online mode affected both the clarity of the system's audio and the ability to observe the learner's facial expressions. In the online mode, learners were not always able to hear the system's audio clearly

("The sound is not clear", or they physically brought their ears close to the device) and the experimenter had to re-pronounce the target word to enable them to proceed.

In term of **learners**, a majority of learners in both groups were engaged and motivated. They reported that the system was "better than the textbook" and cited reasons such as "because it has audio", "because it has audio and I can choose", "I liked it because there is a challenge to win and better than the textbook because it has audio", "because it let me know my mistakes". Therefore, the audio feature was the dominant reason for their engagement and motivation towards the system. However, later sessions were affected negatively. For instance, one learner was tired and demotivated because the session was conducted almost at the end of the school day. Another learner was also demotivated because the session took place during the school's play-time.

In addition, two findings were noted in term of **choices**:

– All learners in both groups (except one in the mismatched group) tried to figure out the correct choices by both concentrating on the spoken target word and spelling it out. Removing the short vowel from the last letter of the target word was a surprising way which one of the learners followed to help her figure out the correct choice. Using their finger to spell out the target word on the table was another method used. Two learners (one learner from each group) benefited from the displayed image.
– Five learners in each group insisted that their wrong choices were correct or they lost focus on the task.
– Three learners in the mismatched group and one in the matched group realised their errors before completion. They completed the remaining exercises quickly and randomly in order to start afresh.
– One learner in the mismatched group focused on points and became happy each time she gained one.
– One learner in the matched group faced difficulty in choosing the correct choice and complained "The choices are too similar".

Finally, in term of **training activities**, none of the learners in either group was able to complete all of the eight activities on the first attempt. They repeated some of these activities many times until they succeeded. This repetition had both positive and negative effects:

– *Positive Effects*: Three learners in each group increased their focus in later attempts in order to succeed. In addition, one learner in the matched group was able to recall their mistakes and thus avoid repeating them. Three learners in the mismatched group and five in the matched one were able to memorize their correct choices and thus re-choose them quickly and without re-listening to the target word. However, one of the learners from the mismatched group fell into the trap of memorizing the position of the correct choice instead of the choice itself without noticing that the position of the choices changes each time.

– *Negative Effects*: Four learners in the mismatched group and five in the matched one became bored during some of their sessions. Three learners in the mismatched group and two in the matched one lost their focus and switched to choosing their answers randomly – perhaps to either waste time or to win by chance. Some of them required more than one experimental session to complete a single training activity. As a result, five learners in each group were not able to complete all eight training activities during the eight experimental sessions. One learner (in the matched group) completed half of the activities while the others completed between six to eight activities.

One learner (in the mismatched group) reported that "it is hard and I prefer to use paper". This learner also took breaks in the sessions and was agitated.

4 Experiment 2: Reading Skill Level Adaptivity

This experiment aims to understand the impact on reading performance of adapting learning material based on the reading skill level of learners with dyslexia. The effect on satisfaction of learners with dyslexia is also presented.

4.1 Experiment's Questions and Hypotheses

This experiment addresses the following questions:

Q1: **Does adapting learning material based on reading skill level of learners with dyslexia improve reading performance compared to non-adapted material?**

Q2: **Does adapting learning material based on reading skill level of learners with dyslexia achieve a higher level of learner satisfaction compared to non-adapted material?**

Two hypotheses were formulated for this experiment:

– ***H1:*** Adapting learning material to the reading skill level of learners with dyslexia achieves significantly better learning gain compared to non-adapted material.
– ***H2:*** Adapting learning material to the reading skill level of learners with dyslexia achieves significantly better learner satisfaction compared to non-adapted material.

4.2 Measurements and Data Collection

Two measurements were used in this experiment. Reading performance was assessed directly after finishing the experiment to derive the learning gain. Learner satisfaction was also measured.

Data was gathered using several tools: reading skill level diagnostic tests, reading tests (pre- and post-tests) and a satisfaction questionnaire. The reading skill level tests were used to determine the reading skill level of the learner.

Three basic tests were used to determine the reading skill level of learners: reading letters with the different short vowels (S1), reading words with Sakin letter(s) (S2) and reading words with short vowels and Sakin letter(s) (S3).

Pre- and post-tests are commonly used to derive learning gain. Here, these included different vowelized words from the curriculum and were validated by special education experts. Each learner was asked to read these words aloud to measure their performance. The pre-test was applied at the start of the study to balance the experimental conditions. At the end, the same test was used to re-assess the learner's performance (post-test). The learning gain is the difference between the pre-test score and the post-test score.

Learner satisfaction was measured using a reliable and validated tool, the E-Learner Satisfaction (ELS) questionnaire [42]. ELS measures overall satisfaction of learners with e-learning systems [42]. The test uses ten questions adapted to a 5-point scale using the Smileyometer [3], a widely-used instrument which matches children's cognitive abilities with these scales (awful, not very good, good, really good and brilliant) [36].

4.3 DysSkillTrain System

The Dyslexia Skill Level Training system (*DysSkillTrain*) was designed to support the aim of this experiment. It is a dynamic, web-based e-learning system. There are two versions to support the two experimental conditions. The adaptive version of the system matches training material to reading skill level, and the non-adaptive version provides a combination of training material at all reading skill levels. Both versions of the system were identical; the only difference is the curriculum.

The system provides six different reading sessions each with 20 training activities (a total of 120). The difficulty gradually increases in both versions. The content of the training material was drawn from the school curriculum to target the three skills (S1, S2, S3). For S1, the reading material includes reading letters with the different short vowels progressing from the simple short vowel (fat-ha (/a/)), (kasra (/i/)) to the advanced short vowel (dammah (/u/)). For S2, the reading material includes reading words with Sakin letter(s) progressing from simple words (with one Sakin letter at the end of two-letter words) to advanced ones (i.e. two Sakin letters in the middle or at the end of three- and four-letters words). A Sakin letter is a letter with a sukun on top of it (indicated by a small circle) which is a letter with no vowel. For S3, the reading material includes reading words with short vowels progressing from simple words (i.e. words of three letters with only the fat-ha short vowel) to advanced ones (i.e. words of three- and four-letters with a mix of all three short vowels and Sakin letters).

Fig. 3 shows an example of a training session for S1. It follows the same procedure as *DysTypeTrain* in presenting the question, target word and its audio icon, three choices (one correct) and the training progress bar. Motivational feedback is presented, if they choose the correct answer, and remedial feedback in the case of choosing a wrong answer. Additionally, motivational messages and the total point score are presented after completing the activities. The training sessions' layout for S2 and S3 is consistent with those for S1; that is keeping the question, target word and its audio icon and the choices in the same place. The only difference is the training material for each skill.

Fig. 3. A screenshot of one of the DysSkillTrain system training sessions.

4.4 Method

The experiment took place in Jeddah, Saudi Arabia. Before conducting the experiment, learners were welcomed and introduced to the objectives of the experiment. Their demographic information was collected, their reading skill level was determined and their initial reading performance was assessed by the pre-test. The learners were divided into two groups, balanced by age, grade, and pre-test score. The control group used the non-adaptive version of the system, while the adaptive group used the adaptive version.

The experiment took place in person, in a quiet room, within the learner's school. Neither the learner nor the experimenter was aware of the experimental condition to which the learner had been allocated. The learner sat in front of a desk with a laptop with the experimenter next to them. The experimenter explained the *DysSkillTrain* layout. Learners worked individually. There were six sessions: two sessions per learner per week. Each session had a duration of approximately 30 minutes. After finishing the experiment, the post-test and ELS tool were administered.

4.5 Participants

Originally, 44 female, native Arabic speakers, already diagnosed with dyslexia, were recruited. Due to the closure of schools (COVID-19), this number dropped down to 41, who completed the experiment. Learners were aged from 7-10 years

(Grade 2 to 4). They had previous experience with electronic devices. The learners were assigned to the control group (n=21) or the adaptive group (n=20) balanced by age and grade. All learners had approximately the same prior reading skill level with no statistical difference between groups (mean score of pre-test for the adaptive group=3.9, SD=1.74, mean for the control group=4.19, SD=1.99).

4.6 Results

Both adaptive and control groups were homogeneous in terms of gender, language, age and pre-test. The data were analyzed using the IBM SPSS statistical software.

Learning Gain Hypothesis 1 about learning gain was tested. As shown in Fig. 4, the post-test and learning gain of the adaptive group were higher than the control group. The findings indicate that there was generally a positive effect in adapting learning material to the reading skill level of learners with dyslexia. The

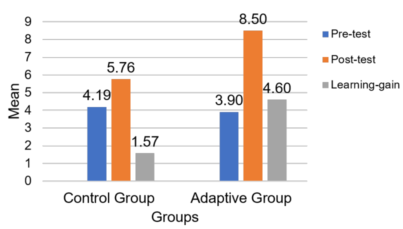

Fig. 4. Results of pre-test, post-test and learning gain of the control and adaptive groups.

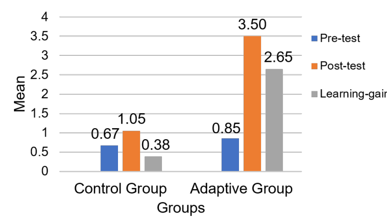

Fig. 5. Results of unseen words pre-test, post-test and learning gain of the control and adaptive groups.

significance of the learning gain was tested. The data deviated from a normal distribution, as assessed by Shapiro-Wilk's test ($p<0.05$), so an independent sample Mann-Whitney U test was used to determine if there were differences between the groups. The results indicate that the learning gain for the adaptive group (mean ranks=29.18) were statistically significantly higher than the control group (mean ranks=13.21), U=373.5, $p=0.000017\approx0.00$, Z=4.307. Therefore, the first hypothesis is confirmed, and it can be concluded that adapting learning material to the reading skill level of learners with dyslexia yields significantly better learning gain than in the non-adaptive condition.

Additional Findings The previous subsection demonstrated the benefit of training learners with dyslexia when reading known words. Whether this can be generalised to unseen words is investigated in this subsection. Fig. 5 shows that the mean scores for unseen words in the post-test is higher in the adaptive group. As the data deviated from the normal distribution, as assessed by 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 scores for the adaptive group (mean rank=29.75) were statistically significantly higher than for the control group (mean rank=12.67), $U=385$, $p=0.000002\approx0.00$, $Z=4.714$.

Learner Satisfaction Based on the analysis of the learners' satisfaction, shown in Table 1, the adaptive group (Mean=4.77, SD=0.13) had a larger mean satisfaction score than the control group (Mean=4.22, SD=0.44), indicating that there was a positive effect on learner satisfaction when learning material was adapted to their reading skill level.

Table 1. Satisfaction scores of learners with dyslexia.

ELS components	Satisfaction of control group		Satisfaction of adaptive group	
	Mean	SD	Mean	SD
Learning content	4.20	0.91	4.63	0.59
System personalization	4.68	1.23	5	0
System interface	4.24	0.88	4.76	0.47
General satisfaction	4.22	0.44	4.77	0.13

As the learner satisfaction score distributions of both adaptive and control groups were normally distributed (Shapiro-Wilk's test $p>0.05$), an independent-sample t-test was used to investigate if there were statistically significant differences in satisfaction score between the two groups. Results indicated that the learner satisfaction score for the adaptive group, $t(23.37)=5.38$, $p=0.000017\approx0.00<0.05$, was statistically significantly higher than the control group. Therefore, the second hypothesis is confirmed and it can be concluded that adapting learning material to the reading skill level of learners with dyslexia yields significantly better learner satisfaction than in the non-adaptive condition.

5 Discussion

This research was affected by COVID-19. It decreased the number of learners and negatively affected the process of observing the learners.

The observation showed that learners were engaged and motivated to learn. This is consistent with the high learners' satisfaction scores with the *DysType-Train* system [1]. There is a strong relationship between learners' motivation and satisfaction [26]. Almost all learners followed the same method in figuring out the correct choice by concentrating on the spoken target word and decoding it.

The repetition feature embedded within the system enhanced the short-term memory of the learner through their memorizing the correct choices. This is in line with previous studies where repetition is shown to be useful for learners with dyslexia [5] and increases learning effectiveness and can be used along with prior knowledge and time spent as strong predictors for good results [25].

In addition, this research confirms that adapting to learner's reading skill level is one factor that can enhance learning. This is in line with previous studies, which have argued that learners' knowledge and skill level should be considered [19, 27, 43]. This study differs from existing work targeting dyslexia, which either lacks formal evaluation [4, 10, 11] or where the size of the sample is small [11].

Finally, the results follow the argumentation of Kangas et al. [26] that there is a strong relationship between learners' motivation and satisfaction, where satisfaction is influenced by the learning content. This experiment showed that learners with dyslexia were more satisfied when adapting learning material according to their reading skill level. This is in line with a previous study [3]. The system interface was identical between the two conditions, but the interface component in the ELS was rated more highly in the adaptive condition, as well as the learning and system personalization components. It is a useful way to assess how well the learning matches the learners' needs. While they may not be able to explicitly assess this match, they are, at least subconsciously, aware of it and this will be reflected in their assessment of aspects of the system that do not change between conditions.

6 Conclusion and Future Work

This research investigated the impact of adaptation based on learners' dyslexia type and reading skill level. Adaptation of learning material according to these two important characteristics of learners with dyslexia [21, 27] is still a significant gap in existing research, especially in Arabic [2, 12]. Arabic dyslexia was targeted in this research since there are few studies in this language [11, 30]. This research also addressed the lack of rigorously designed and controlled experimental evaluations in previous studies [4, 11]. One experiment targeted learners' dyslexia type and the other learners' reading skill level. A mixed-methods approach of qualitative and quantitative analysis was used.

The first experiment aimed to investigate the impact on the behaviour of learners with dyslexia, when adapting learning material based on dyslexia type. It was conducted with 16 Arabic learners with dyslexia. The qualitative findings of this experiment revealed that the majority of learners were motivated and engaged. This is consistent with the learner's satisfaction with the *DysTypeTrain* presented in [1]. There is a strong relationship between learners' motivation and satisfaction [26]. In addition, presenting the target word in different modes (audio and visual) was beneficial. Many learners insisted on the correctness of their errorful answers and it might be useful to add audio feedback to remedy this. It was also clear that many learners had additional problems that affected their ability to study. Despite the positive results of this experiment, there are several limitations. One is the small number of learners. Therefore, it is not possible to generalize the findings.

The second experiment aimed to investigate the impact on reading performance of adapting the learning material based on the reading skill level of learners. It was conducted with 41 Arabic learners with dyslexia. The quantitative results of this experiment revealed that adaptation based upon learners' reading skill level leads to a significant improvement in learning gain and satisfaction. This is in line with classroom practice [17] where, once the learner's reading level has been determined, teachers select the most appropriate materials for each learner [17]. Moreover, the current findings indicated that learners' reading performance showed the greatest degree of generalization when learning materials were matched to the learners' reading skill level. More importantly, in contrast to previous research [11], this experiment is one of the few studies which consider a combination of learning effectiveness and learners' satisfaction as metrics with a significant number of learners.

Reading speed is a good indicator of reading fluency. In the future we will include reading speed, as one important metric. A limited number of reading skills are covered in this study. This was an appropriate decision but in the future, we will extend the research to cover, for instance, long vowels and sentence level reading. Further investigation of other metrics, such as reading speed, as mentioned, is also required.

The complex co-morbidities of many learners with dyslexia suggests that adaptation based on other factors (e.g. learning style or personality) would be valuable. Similarly, in this work there are a limited number of gamification elements and these are fixed across each experimental condition. Adapting the gamification elements to match the, often complex, needs of individuals in this population is an important area of future research [24].

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