Unobtrusive monitoring of learners' game interactions to identify their dyslexia level

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***Abstract*—Several research studies have highlighted that the traditional method of identifying dyslexia within learners is time consuming, expensive and might not be effective as some people acquired the skills to hide their disability. Particularly, no tool or method was reported in the Arab region (22 countries) that could help identify dyslexia within Arab learners. Therefore, this paper presents a developed and validated educational game to implicitly identify the level of dyslexia within learners based on their game play traces. The game was played by twenty-six children within a private school for special education with the supervision of experts from a private center for learners with disabilities. The obtained results showed that the accuracy level of identifying learners with dyslexia with the use of the game is high. Additionally, the experts reported a favorable perception and high technology acceptance degree towards the game. The findings of this research could enhance the educational technology field by providing an educational game design for implicit identification of dyslexia level.**

Keywords-component: Disability; Educational games; Specific learning disorders; Dyslexia; Visual-spatial attention; Phonological awareness

I. INTRODUCTION

According to the World Report on Disability, published by the World Health Organization (WHO) and the World Bank, the number of people with disabilities over the globe is almost 2 billion (37.5% of the world's population) [1].WHO defines a person with disability as anyone who has "a problem in body function or structure, an activity limitation, has a difficulty in executing a task or action; with a participation restriction." One of the disabilities is dyslexia which has been a subject of debate for many decades and still continues to be a contentious topic [2]. This debate covered the types of dyslexia and its signs. The Board of Directors of the International Dyslexia Association (IDA) [3] defined dyslexia as:

"a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge."

Several researchers have thought of using computer assistive technologies to help dyslexic learners, since high number of them are dropping off from schools due to the schools are incapable of keeping up with their personal needs [4]. Specifically, several researchers used educational games as they are fun, interactive and can easily increase learners' motivation and engagement level while learning. However, most of these games focused mainly on the learning process by helping learners with dyslexia learn, but not on the identification process of dyslexia within these learners. In this context, Casale [5] mentioned that the traditional tools to identify dyslexia are expensive, time consuming and learners acquired the skills to trick these tools and hide their disabilities. Particularly, in the Arab region (22 countries), it is seen the absence of tools and methods in Arabic to help experts identify dyslexic Arab learners or even help them learn [6].

Therefore, this study presents an on-going international project about enhancing learning disability and accessibility worldwide and particularly in the Arab region (22 countries). Specifically, this study presents a new innovative way of implicitly modeling the dyslexia level of learners based on their traces collected while playing the proposed educational game. To the best of our knowledge, no educational game is reported in the literature which aims to model the dyslexia level of learners. The findings of this study can help advance learning outcomes for dyslexic learners. It can also advance

2161-377X/20/$31.00 ©2020 IEEE
DOI 10.1109/ICALT49669.2020.00040

the game design field by providing new innovative ways to model dyslexia level using learning-game traces.

The rest of the paper is structured as follows: Section II presents a literature review on the educational games for dyslexic learners. Section III talks the design and the development of the proposed educational game. Section IV presents the conducted research method to validate the game. Section V discusses the obtained results. Finally, Section VI concludes the paper with a summary of the findings, limitations and potential future directions.

II. Literature Review

Dyslexia is a specific learning disability of written language. It is the most common disorder of learning disability. It is constitutional, and probably genetic, without intellectual deficit, sensory, neurological, environmental or motivational deficiency [7]. Children with dyslexia may read poorly for several reasons, including emotional balance, pedagogical errors, individual and social maturity of the child and the cerebral cortex [8, 9]. Recent research suggests that in addition to skills with pronunciation, visual-spatial attention may be an important predictor of reading abilities [10]. It is also argued that reading deficits mainly derives from an erroneous categorization of sounds forming words, caused by impaired capability to discriminate among acoustic features of different sounds and phonemes [11].

Several researchers have highlighted the importance of using computer supported technologies to help children with dyslexia learn [4]. Particularly, games have been used as they can keep learners motivated and increase engagement level. For instance, Kyle et al. [12] developed a game where the player hears either sounds or words and then he/she has to match those to visual targets (letters and sequences of letters) shown on the screen. The obtained results showed that the game may enhance the decoding abilities of students. Rello, Bayarri and Gorriz [13] developed Dyseggxia which is a game application with word exercises for children with dyslexia. In this game, the exercises are designed by using the analysis of written errors made by people with dyslexia and presenting Spanish reinforcement exercises in the form of a computer game. Richardson and Lyytinen [14] created a game called "GraphoGame" which was developed to identify children at risk of having dyslexia before school age in Finland. Its exercises are aimed towards the connection of graphemes (letters) and phonemes (sounds) to improve reading. Franceschini et al. [15] also investigated whether computer action games help children with dyslexia to improve their ability of decoding words. In a between-group design experiment with 20 children, they observed that 10 children playing action games for 9 sessions (80 min each) improved their reading skills significantly more than the control group that played non-action games. They claimed that action games improve the children's spatial and temporal attention, which is essential for decoding words.

Despite, that several technologies, including games are designed to help children with dyslexia learn, researchers highlighted that dyslexia diagnosis is expensive, time consuming and children are now becoming smarter in a way that they can hide their disability on screening tests developed for use in the general adult population [5]. Finally, it is seen that no innovative technologies are developed in the Arab region for learners with disabilities, including dyslexic children. Elbeheri, Mahfoudhi, and Everatt [6] mentioned that there is no specific Arabic method and tool that can be used by experts to identify, assess, or diagnose dyslexia. Similarly, there is little work on intervention methods that can be used specifically for dyslexic individuals learning to read and write in Arabic. Therefore, this study presents a newly developed game to implicitly model the dyslexia level of Arabic children.

III. Game Design

The designed game is an educational game which aims to enhance the subjects' visual-spatial attention, to teach how to decode and distinguish letters resembling in writing and phonemes to develop their phonological awareness and implicitly model Dyslexia level within learners. The game was developed under the supervision of the experts. Specifically, this game is composed of two levels. The first level aims to identify *disorder of spatial orientation.* This level involves a visual search, which implies the ability to process some stimuli. The process is the result of a child's ability to focus and to get the right orientation to solve the game. As Figure 1 shows, the learners will find themselves in the middle of a maze with a simple design so that they can focus on the orientation problems in individuals and avoid other elements that can distract them. The learners have to find the exit path by moving in four directions (up, down, right, left) with the keyboard arrow keys.

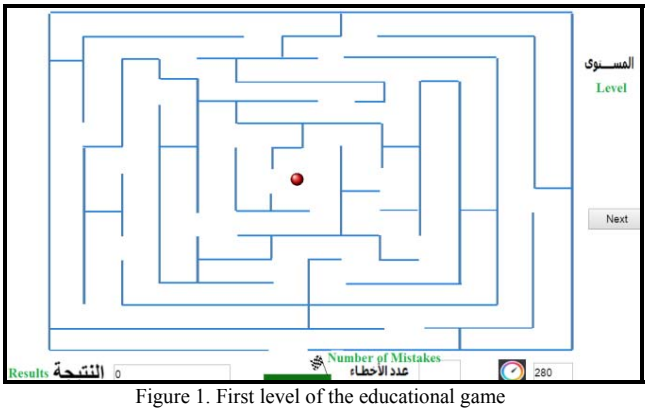

Figure 1. First level of the educational game

The second level aims to identify *phonological awareness (confusion between letters and sounds)*. In this context, several words (e.g., ضجيج and صخب) are played to the learners with letters which are similar in pronunciation but different in writing (ص/س), or with letters which are almost similar in writing but different in pronunciation (ج/خ, ض/ص). Then the learners have to write down the word with the given letters. For instance, as Figure 2 shows, the learners have to drag and drop the balloons holding the letters and put them in order on the balloon holders (1, 2 and 3). To model the level of Dyslexia within learners, several variables are collected from the game, as listed in Table I.

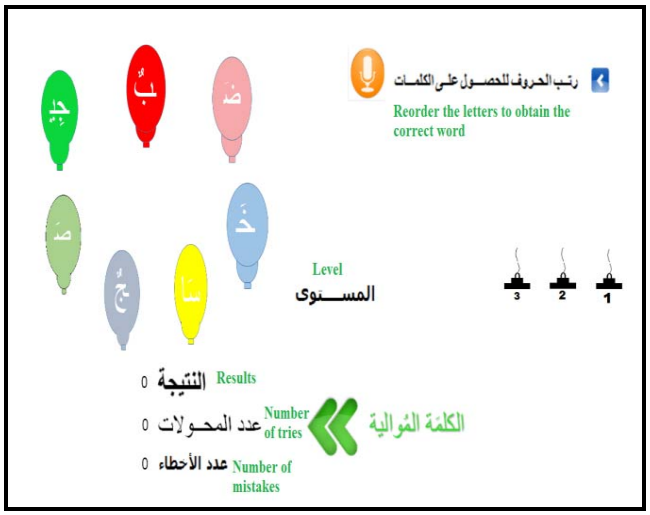

Figure 2. Second level of the educational game

TABLE I. GAME VARIABLES TO MODEL DYSLEXIA

Game level	Variable
Level 1	**Time** taken by each player to find the exit.
Level 1	The number of **closed path** travelled.
Level 2	Obtained **score**, based on the given correct answers.
Level 2	The number of **attempts** to listen to the words.
Level 2	The number of **false response**.

These variables were then analyzed by the game-based association rules given by seven experts in the field which are speech therapists, neuropsychologists and pedagogical advisors. Examples of these association rules are given in Table II.

TABLE II. EXAMPLES OF ASSOCIATION RULES TO MODEL DYSLEXIA

Variable	Examples of association rules

Time + **Path** + **Score** + **Attempts** + **Errors**	If time ≥ 6min & Path ≥ 5 Then
	If Score = 0 & Attempts ≥ 5 & errors ≥ 5 Then
	➔ the level of dyslexia is **high**
	
	If time ≤ 3min & Path < 3 Then
	If Score = 20 & attempts < 3 & errors < 3 Then
	➔ the level of dyslexia is **low**
	
	If 3 min < time < 6mn & 3 ≤ Path < 5 Then
	If Score = 10 & 3 ≤ attempts < 5 & 3 ≤ errors < 5 Then
	➔ the level of dyslexia is **medium**

IV. METHOD

This section aims to validate both the game design and accuracy in modeling the Dyslexia level within learners.

A. Participants

A 2-week experiment was conducted at two places, namely: (1) the first center in Tunisia which offers educational support, psychological and speech therapy for dyslexic children; and, (2) a private primary school exclusively reserved for children with learning disabilities, including dyslexia. Precisely, seven experts (speech therapists, neuropsychologists and pedagogical advisors) and twenty-six learners (11 girls and 15 boys) with average age of 8 years (i.e., ages between 7 years and 10 years) participated in this experiment (See Figure 3).

Figure 3. A dyslexic child playing the educational game

B. Procedure

The experts started with giving learners a valid paper-based test in the literature to model their level of dyslexia (detailed in the next subsequent section). This test consists of oral reading and spelling exercises. The learners then played the game for 10 to 15 minutes with the assistance and observation of the experts. Finally, the accuracy of the game in modeling dyslexia level was calculated by comparing the modeling results obtained from the game with the one from the paper-based test. Additionally, based on the learners' game play experience, the experts filled a technology acceptance questionnaire and participated in unstructured interviews with researchers. Details of these instruments are given in the next section.

C. Instruments

During the experiment, the following instruments were used.

- Paper-based test: The experts used the Alouette test where the child had to read aloud a text without real meaning, composed of linguistic structures conforming to a language but sometimes relatively rare and also infrequent words [16]. The experts also used the sub-test "identification of written words" where the child has to match the images to the given words [17].
- *Technology acceptance questionnaire:* To evaluate the experts' perceived technology acceptance levels toward the educational game, a 5-point Likert scale questionnaire was developed. This questionnaire contains twelve statements (3 for each dimension) and covers

four dimensions highlighted by Davis [18], namely: Ease of use (EOU), Usefulness (U), Attitude toward using the game (ATT) and behavioral intention towards use the game in the future. The above four dimensions had a Cronbach's alpha value 0.71, 0.79, 0.88 and 0.75 respectively. This implies that the questionnaire is reliable [19].

- Unstructured interviews: It was used to collect the opinions of the experts regarding the developed educational game. This instrument is very flexible and allows participants to give researchers their most honest and direct opinions. In the 15-miniute interview, the experts talked freely about the importance of the game. The interview was recorded in order to be analyzed and draw conclusions. The coding process was done by two researchers, and in case of disagreement, the two researchers resolved it by discussion. Table III lists the coding scheme and their definitions for the coding process.

TABLE III. CODING SCHEME OF THE INTERVIEW QUALITATIVE ANALYSIS

Code	When to use
Advantages	Use this code when the experts mention some advantages of the developed educational game.
Enhancement	Use this code when the experts mention some points that should be enhanced in the developed educational game.
Consideration	Use this code when the experts mention some points that should be further concerned in the next version of the game.

V. RESULTS

The accuracy of the dyslexia modeling with the game, experts' perceived technology acceptance levels and their perceptions toward the game are presented in the next subsequent sections.

A. Dyslexia Identification Accuracy

To evaluate the accuracy level of the dyslexia modeling results with the game, each learner's result is compared to his/her results obtained from the paper-based test. Accuracy is defined as the percentage of correctly classified learners and it is calculated using the below formula:

$$Accuracy\ \% = (correctly\ predicted\ class / total\ testing\ class) * 100$$

As Table IV lists, only 8 learners (out of 26) had wrong dyslexia identification compared to the paper-based test (already validated instrument). Consequently, the accuracy level of the identification process was high (70%). To further determine the agreement degree between the developed game and the traditional method used by the experts for dyslexia identification, the kappa (k) value is calculated [20]. It is used to validate newly developed instruments. According to Landis and Koch [21], kappa value is smaller than 0 indicates no agreement, value is between 0.0 to 0.2 indicates slight agreement, between 0.21 to 0.40 indicates fair agreement, between 0.41 to 0.60 indicates moderate agreement, between 0.61 to 0.80 indicates good agreement, and from 0.81 to 1.0 indicates perfect agreement. The obtained results showed that the game had a "moderate agreement" since k is 0.58.

TABLE IV. ACCURACY RESULTS OF MODELING DYSLEXIA

Number of learners	Correct results	Wrong results	Accuracy
26	18	8	70%

B. Technology acceptance level

The results of the experts' perceived technology acceptance towards the game are presented in Table V.

TABLE V. RESUSLTS OF ECHNOLOGY ACCEPTANCE DEGREE

		EOU	U	INT	ATT
1	**Strongly Disagree**	0%	4.7%	0%	0%
2	**Disagree**	0%	0%	9.4%	0%
3	**Neutral**	9.4 %	9.4%	0%	4.7%
4	**Agree**	43%	62.6%	33.3%	33.3%
5	**Strongly Agree**	47.6%	23.3%	57.3%	62%

As shown in Table V, it is seen that the experts have perceived high acceptance towards the educational game as a new technology to model learners' dyslexia level according to the game play. Particularly, it is seen that 90% of them agree or strongly agree that they will use the game again in the future. To conclude, the proposed game, according to the experts, could be a potential solution to help in the dyslexia identification process.

C. Perception of experts towards the educational game

Based on the coding scheme (see Table III), the coded results were then classified into two categories, namely (1) *effectiveness*, which describes the effectiveness of the game; and, (2) *improvements*, which covers the things that should be enhanced in the game and future elements to be considered. Each category was then used for better understanding the perception of experts towards the game, as follows:

Effectiveness: The experts mentioned that the game is very interesting and effective in identifying the dyslexia level within learners. Particularly, they mentioned that this game is interesting because of the lack of tools for dyslexic Arabic learners. Additionally, another expert explicitly mentioned that "our rehabilitation is essentially based on fun activities and tests in order to take out the child from the classical method of rehabilitation, and this game fulfilled our main goal."

Improvement: The experts further mentioned some design enhancements to consider. For instance, they

mentioned that dark colours should be used more, as well as attractive background screen, for the first level. One of the experts also mentioned that this game is not adapted to all types, because some dyslexic children might have coordination disorder in space, consequently the use of keyboards will be incomprehensible to them.

To conclude, it is seen that the experts have positive perception towards the game. However, further improvements were raised that should be considered in the next version of the game.

VI. Conclusion And Future Directions

This paper presented a newly developed educational game that can identify the level of dyslexia within Arabic learners based on their game play. The game was validated by comparing the identification results of the game with the results of a traditional identification method. The obtained results showed that the game has a high accuracy rate compared to the traditional method with a "moderate" agreement. Additionally, the findings showed that the experts have positive perception and high technology acceptance degree towards the game.

The findings of this study could enhance the field of educational technology by presenting new instrument that could help in identifying dyslexia level within learners. The findings could also advance the game design and development field by reporting game design details for implicit dyslexia identification based on game traces collected during the learning-playing process.

However, several limitations should be acknowledged and further researched. For instance, the sample size during the experimental validation was limited (only 26 children). Additionally, the educational game used predefined association rules recommended by the experts, without using an analytics system (with different algorithms in the background).

Future research directions could focus on making the game smarter by developing a learning analytics system, based on several algorithms, to analyze the collected traces and generate a dashboard about the learners' performance and dyslexia level while playing the game. This could enhance the accuracy degree of the identification process of dyslexia. Additionally, multiple language support (e.g., English, etc.) should be considered to make the game reusable with non-Arabic learners as well.

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