A Review on Assistive Technologies for Students with Dyslexia

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Abstract: Last decades have seen tremendous change in education under the influence of the digital technologies. Education no longer relies on traditional methods; it rather makes use of modern technologies. This paper presents an overview of the recent research on the use of assistive technologies in education with emphasis on students with dyslexia, a specific learning disability referred to as a reading disorder which can also affect writing, spelling, speaking and reasoning. The aim of this paper is to provide an overview of the proposed technological solutions as well as the recent research on technologies and methods used to teach dyslectic students language skills, such as reading and writing.

1 INTRODUCTION

Difficulties learning to map letters with the sounds of one's language, or to read printed words is often called dyslexia, and is one of the most common manifestations of specific learning disorder (American Psychiatric Association, 2013).

The word dyslexia comes from the Greek words dys (weak or bad) and lexsis (language, word) (Croatian Dyslexia Association, 2014), and like many medical and educational constructs, has definitional challenges (Stoker, et al., 2019). However, the basic notion of dyslexia, described as a difficulty in reading which is often unexpected in relation to other cognitive abilities has reminded constant across most definitions definitions (Shaywitz, Morris & Shaywitz, 2008; Lyon, Shaywitz & Shaywitz, 2003; American Psychiatric Association, 1994). Moreover, it is most commonly recognized as a specific learning disability that is neurobiological in origin, which primarily affects reading and writing skills, characterized by difficulties with accurate and fluent word recognition, poor spelling and decoding abilities abilities (Lyon, Shaywitz & Shaywitz, 2003; American Psychiatric Association, 2013; British Dyslexia Association, 2020), in addition to difficulties in phonological awareness, verbal memory and verbal processing speed (Rose, 2009). World Health Organization (2011) describes it as a specific learning disability marked by specific impairments in information processing which result in difficulties in listening, reasoning, speaking, reading, writing, spelling, or doing mathematical calculations.

Being a life-long condition, early identification and treatment of dyslexia are associated with improved outcomes academically and quality of life (Stoker, et al., 2019). Therefore, dyslexia has been the focus of considerable interest for transdisciplinary studies, including the development of assistive technologies, trying to develop rational and effective therapy to enable successful outcome. Moreover, current assistive technologies are mostly available in English, however, there are several specifically designed for other languages.

The remainder of this paper is structured as follows: section 2 describes early signs and prevalence of dyslexia. Section 3 provides an overview of the available technologies, section 4 describes the future work and section 5 closes with conclusion and discussion.

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2 BACKGROUND

2.1 Early Signs of Dyslexia

Dyslexia involves much more than lagging behind in learning to read. The etymology of the name dyslexia expresses the difficulty in using words, how to identify them, what they signify, how they are pronounced and spelled (Miles & Miles, 2004). Students identified with dyslexia have problems in identifying speech sounds and learning how to relate those to letters and words. Moreover, they typically display several key attributes, including: (a) difficulty with word reading, (b) difficulty with spelling, (c) phonological processing difficulties, and (d) slow and laborious reading (Stoker, et al., 2019). Therefore, dyslectic students tend to avoid activities that involve reading; they also show problems in remembering the sequence of the things and most usually are not able to sound out the pronunciation of (more or less) unfamiliar words (Mayo Clinic, 2017).

2.2 The Prevalence of Dyslexia

Experts have estimated that 5-10% of school-age children fail to learn to read in spite of normal intelligence (Habib, 2000), and 10% of the population (or up to 20% depending on definition), suffer from such condition (Habib, 2000; Skiada, et al., 2014).

In addition, there are other disorders similar to or related to dyslexia, including developmental auditory imperceptions, dysphasia, specific developmental dyslexia, developmental dysgraphia, and developmental spelling disability (Stoker, et al., 2019), in fact, reading disability is by far the most common learning disability, affecting over 80% of those identified as learning disabled (Shaywitz, Morris & Shaywitz, 2008).

3 TECHNOLOGY ASSISTED EDUCATION

This subsection presents a literature review of the recent research on the use of technology for students with specific learning disorders, with an emphasis on technologies that are either specifically designed for, or have the features that can be useful for dyslexic students. Even though, there are other possible classifications (e.g. according to language, features, etc.), in this paper these technologies are classified according to the type of devices they are mainly intended for. The first subsection presents desktop software (Table 1), while the second deals with mobile applications (Table 2).

3.1 Desktop Software and Applications

There is a wide range of software specifically designed to assist people with learning disorders, including dyslexia. Most of such software is directed towards enhancing reading and writing skills. For such cause was developed the **Phonological Awareness Educational Software** (PHAES), which presents a hypermedia application for helping dyslexic readers, using phonological awareness training in Greek language (Figure 1).

Figure 1: Example of PHAES interface.

Learning activities present graphemes and corresponding phonemes at the word and sentence level. The PHAES demands only basic computer skills, it is designed with simple graphics and navigation, and is therefore suitable for young learners who can use it with or without supervision. It can be supportive tool for both teaching and speech therapy treatment, and it uses multisensory approach. Moreover, it consists of four phases and tasks are divided according to difficulty. The first stage deals with practicing letter-sound correspondence, in the second stage letters are embedded into words, the third stage introduces sentence formation and in the final stage students are asked to form common words. The software has proved to be educational in early literacy development, moreover participant were motivated and found it easy to use (Kazakou, et al., 2011).

The following study (Staels & Den Broeck, 2015) used **Kurzwiel 3000** as a text-to-speech software to investigate whether orthographic learning could enhance the reading skill for dyslexic children. Effectiveness of the software was analyzed using the phonological recordings. In their study, 65 dyslexic children were asked to read eight stories containing embedded homophonic pseudoword targets in Dutch language (e.g. Blot/Blod, Kowand/Kowant). Participants read stories with and without assistance of the software and subsequently were assessed based on their completion of naming, spelling and orthographic-choice task. This study showed that children with dyslexia can obtain orthographic knowledge through independent silent reading, therefore target spellings were correctly identified more often, named more quickly, and spelled more accurately than their homophone foils. However, a negative effect of text-to-speech software on orthographic learning was demonstrated among younger students who only passively listened to the auditory presentation of the text, because dyslexic students need to participate in active reading to enhance their reading skills (Share, 1995).

Moreover, another research (Alsobhi, Khan & Rahanu, 2014) showed that generic e-learning applications are not as effective with dyslexic learners because what might be required are specific learning applications that are tailored for specific categories, depending on the dyslexia type. In addition, even though assistive software facilitate learning to some extent, there are other preconditions that need to be in place to successfully implement technology in learning process (Goumopoulos, et al., 2018), such as availability of digital course material, the possibility/authorization to use software during classroom courses, as well as sufficient training for students to fully use all the possibilities these assistive technologies offer.

Experimental study (Alsobhi & Alyoubi, 2019) presented the same point using a novel dyslexia adaptive e-learning management system - **DAELMS** (Figure2).

Figure 2: Learning materials implemented in DAELMS.

The system correlated each given dyslexia type with its preferred learning style, and subsequently adapted the learning materials which are presented to the student. Being an adaptive e-learning system, the DAELMS incorporated several personalization options: (a) navigation, (b) structure of curriculum, (c) presentation, (d) guidance, and (e) assistive technologies that ensured that the learning experience is aligned with the user's dyslexia type as well as the preferred learning style. The DAELMS was evaluated by the group of university students studying a Computer Science related majors. The participants were presented with course materials related to their field of study (Computer Science). The evaluation results proved that when the system provided the user with learning materials that matched their learning style or dyslexia type it enhanced their learning outcomes.

Another team of researchers (Hall, et al., 2015) developed a **Strategic Reader**, technology based system that incorporated curriculum based measurement (CBM) and a universal design for learning (UDL) aiming to enhance the reading skills of students with learning disabilities. The CBM presents a form of formative assessment (Silberglitt & Hintze, 2005), used to monitor student growth, evaluate performance, and change instruction. On the other hand, the UDL is a framework for instructional design (Kennedy, et al., 2014). It is based on three principles: (a) to provide multiple means of representation, (b) to provide multiple means for action and expression, and (c) to provide multiple means of engagement for students. In addition, the Strategic Reader was created with three components: (a) the CBM to monitor the students' progress, (b) an online forum for discussion, and (c) an interactive, computer-supported reading environment. The participants were 10 teachers, 307 middle schools' students in total, with 64 students identified as those with learning disorder. Teachers could easily create interventions for students due to the flexibility of the tool. The effectiveness of Strategic Reader was evaluated using two treatment conditions for measuring progress (online vs. offline). Results showed that students with learning disabilities experienced a statistically significant score increase in the online progress monitoring condition, they were significantly more engaged by (and with) Strategic Reader, finding many aspects of the tool more helpful than other students (Hall, et al., 2015).

Table 1: Assistive desktop applications for dyslexic students.

Name	Main features	Reference
PHAES	Interactive, multisensory, user-friendly navigation, display difficulty levels	Kazakou, et al., 2011
Kurzweil 3000	Interactive, text-to-speech, spelling-checker, word prediction, translation (powered by Google Translate), bookmarks, text and audio notes, personalized	Staels & Den Broeck, 2015
DAELMS	Incorporated personalization options, adaptive (materials presented to students aligned with dyslexia type and learning style)	Alsobhi & Alyoubi, 2019
Strategic Reader	Interactive, multisensory, incorporated curriculum based measurement, applied universal design for learning	Hall, et al., 2015

3.2 Mobile Applications and Games

In addition to computer software, more recent studies are directed towards the design of mobile applications for educational purposes using playful and targeted exercises to improve the language skills of children with dyslexia. Therefore, the following study (Zakopoulou, et al., 2017) was conducted using **iLearnRW** software (Figure 3), developed to provide individualized intervention through games.

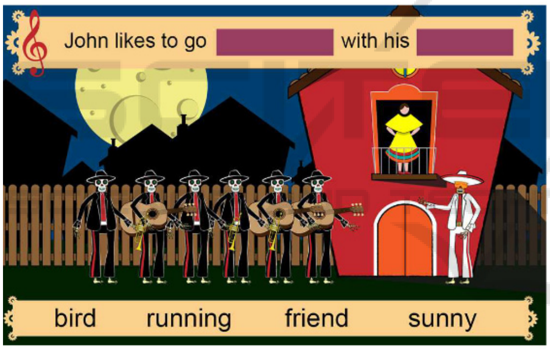

Figure 3: Game activity example: Serenade hero in iLearnRW software.

The software incorporated learning activities, derived by dyslexia experts, that especially addressed language areas that were most challenging for dyslexic students. The game consisted of two modules: a student model and a lesson planner. Individualized intervention was provided through an underlying user profile, which incorporated language features and was constantly updated as the student played games. For each difficulty, the model kept track of the student's skill based on their performance during game activities and the time elapsed since the last practice. The software selected language material based on student's difficulties and progress. The participants were 78 dyslexic students, 9-11 years old. After the 6-month intervention, the students were assessed in order to establish the tool's effectiveness. The results' analysis revealed that there was a strong constructional linkage between the profile entries of the sample, the language content of the tasks of the screening test as well of the games and its effectiveness in the students' performance. In addition, the students who received specific guidance by their teachers, obtained higher success rates in most of the games than those without any guidance.

To improve the educational performances of students with dyslexia, the authors of the following study (Alghabban, et al., 2017) developed a multisensory, cloud based, mobile learning tool. It provided convenient data input and output and was adaptable to fit each student's profile and preferred learning style using pedagogically approved materials with interactive and multisensory approach. Authors conducted a user needs analysis through a literature review, interviews and questionnaires with special educational teachers, dyslexic students and their parents, and offered the architecture with three components: (a) a mobile client, (b) a public network, and (c) a cloud environment to provide the content. The results of this study revealed that the multisensory function supported the needs of students with dyslexia, enhancing their learning progress by almost 30%. In addition, results showed an increase in reading skills after three months of use, and user-friendly interface had positive impact on students' motivation to use the tool. Moreover, interesting, and appropriate presentation of learning materials eliminated boredom and provided helpful mechanisms to aid students' reading ability.

Another interactive mobile application, **EasyLexia** (Figure 4), was developed with the aim to improve dyslexic students' fundamental skills, such as reading comprehension, orthographic coding, short-term memory and mathematical problem-solving using gamification approach.

Figure 4: EasyLexia: Main page layout.

The application was developed for both mobile phones and tablets and was tested among students at a "Speech Therapy Center", located in Syros Greece; however, the application was designed in English language. Preliminary evaluation of this application with 5 dyslexic students (7-12 years old) showed promising results in such contexts as the students showed progress in performance over a short period of time. In addition, results indicated that tablet applications aimed for children with dyslexia, could potentially be more engaging than mobile devices (Skiada, et al., 2014).

Another research (Rello, et al., 2014) integrated teaching materials in an iPad game, **DysEggxia** (Figure 5).

Figure 5: Dyseggxia: derivation exercise (left) and substitution exercise (right).

In contrast to previous approaches, these exercises (in Spanish language) presented the child with a misspelled word as an exercise to solve. These training exercises were created based on the linguistic knowledge extracted from the errors found in texts written by children with dyslexia. To test the effectiveness of this method in Spanish, the study was carried out for eight weeks, 48 children played either DysEggxia or WordSearch, another word game. The children who played DysEggxia for four weeks in a row had significantly less writing errors in the tests than those playing WordSearch for the same time. The results provided evidence that error-based exercises presented using tablets helped children with dyslexia to improve their spelling skills. Moreover, it proved that technology in order to be useful in education must integrate right didactic and pedagogical methods.

In addition, another learning model **LexiPal** (Saputra, 2015) (Figure 6) integrated educational gamification approach for dyslexic children, by incorporating seven gamification elements, namely (1) story/theme, (2) clear goals, (3) levels, (4) points, (5) rewards, (6) feedback, and (7) achievements/badges. The game elements were used with a purpose to encourage dyslexic students while granting desired psychological outcomes when they used the application, including engagement, enjoyment, and motivation.

Figure 6: LexiPal: Example of gamified learning.

The participants in the study were 40 dyslexic students. Based on the observation while students were using the application, most of the students were eager to participate in the evaluation process until it was ended, thus the gamification improved engagement of dyslexic students. On the other hand, quantitative analysis showed that all students enjoyed playing, and most of them wanted to play it again, which indicates that gamification can improve enjoyment and motivation of the children. However, the results are considered as a short-term effect, which is the effect of gamification when and after dyslexic children used the application for short period of time (Saputra, 2015).

Moreover, another research explored potential benefits of gamification using **classDojo**. The educational platform was adapted for the dyslexic students by teachers from dyslexia teaching center. It was used for twelve 1.5-hour lessons. Two main components of the classDojo system were emphasized for this study: (1) awarding of badges, and (2) the reporting system. The teacher could award a badge from a set list of either positive (green) or negative (red) badges. The set of badges was fully customizable for each teaching session, allowing the teacher to tailor the awards for the needs of their students. On the other hand, the report system maintained a record of the badges awarded.

Moreover, a report of a child's badges was automatically emailed to parents every week, as well as comments teachers had written about specific badges. The authors collected data by means of interview (with teachers, students, and parents) and kept daily log of students' and parents' logins to the application. The results indicated that gamification can foster student motivation, in this instance, due to an interaction between a highly customizable design as well as pedagogically tailored appropriation by teachers (Gooch, et al., 2016).

In addition, there are several educational applications designed and adapted to the specifics of the Croatian language, for students with learning disorders and specifically for students with dyslexia. One of the recently developed applications is **OmoReader**, with the OmoType, highly readable font designed within the application, which can be adapted to the individual needs of users. In addition, the application allows words to be broken down into syllables using the automatic syllabification procedure for the Croatian language (Meštrović, et al., 2015), which helps users to read more correctly (Figure 7).

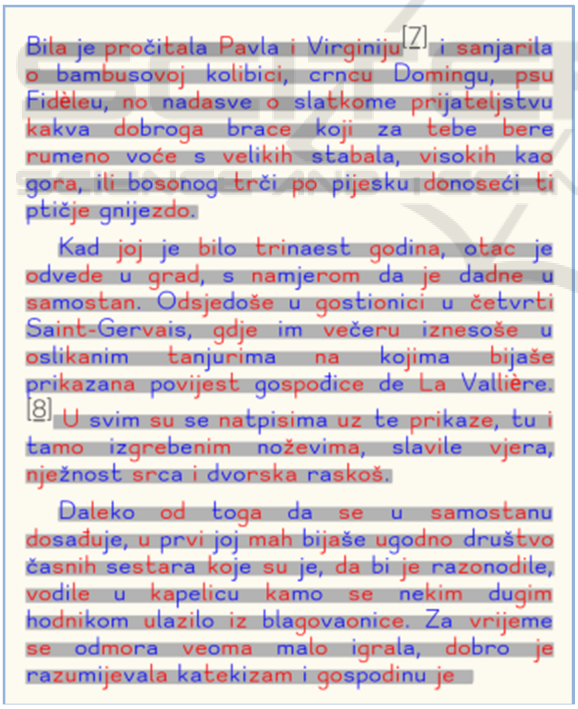

Figure 7: OmoReader interface.

Users can also insert lines in the background of the text to make it easier to follow the text, which helps in staying focused and keeping the reading speed. Within this application, users can also access more than 200 Croatian books, enriched with 3D content, animations, videos, audio, images, and comprehension tasks. The application also supports OCR technology, which recognizes text from various sources, printed and digital. Also, users can convert, edit and save texts using the camera on a mobile device by capturing texts from books, magazines and others printed forms. In addition, data obtained from users is used solely for the purpose of analysis required to develop and improve the application (Šarac, 2019).

Several other applications, also specifically developed for Croatian language, were designed and developed within the project named Competence Network for Innovative Services for Persons with Complex Communication Needs (ICT-AAC), a multidisciplinary project focused on ICT based augmentative and alternative communication. Different experts worked together to create iOS and Android applications, including several specifically designed for dyslexic students, such as Letters, Vocals, Memory, Learning Syllables, Learning Words, Learning to Read (Figure 8), and Language Builder.

Figure 8: ICT-AAC Learning to Read interface.

These applications can be used for direct speech therapy for students with dyslexia, for developing phonological awareness and morphological skills, as well as initial writing skills for young learners. All ICT-AAC applications are visually attractive, provide multisensory access to learning (tasks are accompanied by visual and auditory support, different syllables are highlighted in different colour) and often give positive feedback for correct task completion, which is essential for a sense of success in students with dyslexia (Zorić, 2019).

Table 2 presents the main features of the above mentioned assistive mobile applications for dyslexic students.

Table 2: Assistive mobile applications for dyslexic students.

Name	Main features	Reference
iLearnRW	Interactive, individualized approach (learning materials selection based on student's difficulties and progress), multisensory, gamification elements	Zakopoulou, et al., 2017
Multisensory interface tool	Interactive, multisensory, cloud based, personalized (output aligned with student's profile and preferred learning style)	Alghabban, et al., 2017
EasyLexia	Interactive, multisensory, user-friendly interface, gamification elements	Skiada, et al., 2014
DysEggxia	Interactive, multisensory, user-friendly navigation, gamification elements, included error-based exercises	Rello, et al., 2014
LexiPal	Interactive, multisensory, gamification approach	Saputra, 2015
ClassDojo	The study focused on gamification approach using badges and reporting system, adaptable design	Gooch, et al., 2016
OmoReader	Personalized (preview adapted to students' needs), involved syllabification approach for Croatian language, OCR technology	Šarac, 2019
ICT-AAC applications	Interactive applications developed for different language areas, multisensory, user-friendly visuals, feedback	Zorić, 2019

4 FUTURE WORK

Previous chapters present an overview of the assistive technologies for dyslexic students. Even though all these applications and software are very useful, there is still room for improvement, which is the aim of our future work. Moreover, concerning recent trends in technology and education, an increase in the number of technologies using Artificial Intelligence, Augmented Reality or Game Based Learning can be expected.

In addition, future analysis of assistive technologies implies development of a conceptual model for a system that would support educational processes (both teaching and learning) for dyslexic students.

In order to produce a taxonomy for classification of available technologies, they need to be further analysed with the emphasis on their main features, such as interactivity, multisensory approach, simple graphics and navigation, personalization elements, gamification, and other features considered as important for dyslexic students.

5 DISCUSION AND CONCLUSION

Dyslexia, namely characterized as reading disorder, affects around 10% of population, and is therefore one of the most common learning disorders. It mostly affects language skills that involve reading, spelling, and writing. However, it is not linked to intelligence, or, in other words, dyslexic students' cognitive abilities do not differ from those of their peers, even though they lag behind when it comes to developing language skills, and mainly reading comprehension. As such, reading comprehension is described as the ability to grasp or fully understand information communicated through text. Therefore, dyslexic students mainly lack the ability to comprehend written texts. Moreover, dyslexia has been the focus of considerable interest from researchers in different areas, including neurophysiology, linguistics, educational sciences, computer science and others.

The explosive growth of digital technologies and developments in artificial intelligence have provided powerful possibilities for developing educational aids for students with learning disorders. Also, m-learning, and e-learning have become an influential trend in the educational process. New educational trends promote learning accessibility and flexibility. Moreover, there are additional aspects of these educational trends, as well as assistive technologies, that are especially useful for the students with dyslexia. This paper presents an overview of recent research on the use of technology to assist students with learning disorders, and specifically with dyslexia, both in formal and informal education.

Although there is a substantial amount of research, and applications available for students with dyslexia, there are several gaps that must still be addressed. Firstly, most of available applications are directed towards the enhancing of language skills for native languages. Moreover, applications are mostly in English language, designed for students' whose native language is English. Therefore, there is a little research on how dyslexic students acquire foreign languages, in terms of developing all language skills in English as a foreign language, and furthermore, what are the implications for developing such learning system for dyslexic students whose native language is Croatian.

Another substantial issue pertains to the lack of a comprehensive learning system which would be directed towards enhancing all language skills (reading, writing, speaking and listening). Available applications and software manly emphasize either reading or writing skill and neglect the language comprehension, as a whole. Moreover, educational systems are usually created and designed with the aim to help dyslexic students, however, little number of applications is used after the research. Even though the assistive technologies prove to be useful, and increase students' motivation and self-confidence, in most cases, after the research is over, the teachers and students return to previous educational model.

Moreover, it is not enough for technology to exist in the classroom, it is only beneficial when used appropriately. Thus, effective educational methods must comply with pedagogical requirements. Due to interactive aspect of education, learners should be more involved in the learning process. Therefore, digital technology, used in education, must offer students autonomy with attention to their age, special educational needs, potentials, and preferences. Also, not all methods and technologies are appropriate for all students. They have to match individual's learning style. Moreover, since all dyslexics do not share the same symptoms, each student presents a special case when adopting educational tools. Therefore, there is a strong need to involve individualized approach when developing assistive technology for students with dyslexia.

In addition, effective educational systems for dyslexic students support multisensory approach, which is crucial for improving students' reading skills. In such approach, the same information is presented in different formats (text, image, sound, and other) since students learn best when they use all senses. Moreover, collaborative learning presents another virtue of assistive technologies. In addition to one-on-one learning, technology enables students to collaborate with one another, with teachers, parents, tutors, and other individuals. Collaboration gives students the sense of integration, which is very important for all students, and especially for those with learning disorders.

Furthermore, learning environment needs to be interactive, filled with instructional resources and challenging assignments, enabling students to become engaged participants. Thus, games have become a very effective educational aid for dyslexic students, especially because they use badges (rewards) and points (ranking). These offer a constant feedback and promote competition, which is a highly motivating factor.

After all, new technologies offer a wide range of possibilities for development of educational aids for dyslexic students. They open new avenues through which students with dyslexia can learn and enhance language skills, both in their native and foreign language.

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