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Assistive Mobile Applications for Dyslexia

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Abstract

The ability to read is one of the main skills of a human being. However, some of us have reading difficulties, regardless of social status, level of intelligence or education. This disorder is the main characteristic of dyslexia and is maintained throughout life, requiring early and specialized intervention. Dyslexia is defined as a learning disturbance in the area of reading, writing and spelling. Although the numbers of prevalence rely heavily on the type of investigation conducted, several studies indicate that up to 17% of the world population is dyslexic, and that men have greater prevalence.

In this work we will address the use of assistive mobile applications for dyslexia by analyzing possible solutions and proposing a prototype of a mobile application that can be used by dyslexic and whilst giving feedback both to the dyslexic him/herself and to the assisting technician or teacher. The implemented prototype focuses the Portuguese language and was tested with Portuguese students with ages between 10 and 12 years old.

Preliminary results show that the proposed gamified set of activities, allow dyslexics to improve multisensory perception, constituting an added value facilitator of adaptiveness and learning.

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1. Introduction

Dyslexia is the term used to describe the learning difficulties involving both written and spoken language. It is characterized by great difficulty in learning to read and write, remembering letters, pronouncing words and discriminating specific sounds of letters. As such, it is a disorder that affects the understanding of natural language and also learning other languages.

The ease and time required for learning of reading are related to the nature of the language. Several studies demonstrate that it takes longer to learn to interpret words in languages with phonetically opaque spelling than in languages with phonetically transparent spelling. A transparent language (Finnish, Portuguese, Spanish, and Italian, for example) is one which has a very clear letter-sound correspondence and regularity. In contrast, a deep or opaque language (English, French and Danish, for example) is one which has a more complex phoneme-grapheme correspondence and more irregularities.

The prevalence of dyslexia is reported as up to 17% of the global population suffering from some degree of dyslexia. This work focus on one of the most spoken languages in the world, Portuguese [1], but results can be generalizable, since problems are generic, despite the language-specific solutions.

In 1990 a spelling agreement was signed by all the countries where Portuguese is an official language. As a result, more than 200 million people share the same spelling and most results and materials can be adopted for any Portuguese speaking country. Specifically in Portugal, it is estimated that dyslexia affects 5.4% of the population [2]. In Brazil, that has approximately 83% of Portuguese speakers, despite the fact that is no studies, it is estimated that the prevalence of dyslexia is around 8%. Notwithstanding the number of Portuguese speakers, there is scarce evidence of research and development of assistive mobile technologies specialized in dyslexic reeducation for the Portuguese language.

Mobile technology is present in the daily life of a human being and as the devices become more powerful, extremely functional and low-priced, thus increasing their potential as a tool to support learning. In this context mobile devices may become indispensable as a learning aid for students with special educational needs and for dyslexic in particular. Hence, this work proposes a study of dyslexia and how mobile applications can be useful to help Portuguese speakers with this disorder.

This paper is organized in more four sections. In Section 2, we present an overview and the state of art on dyslexia and re-education through games for mobile devices. In Section 3, we describe our proposal for a prototype of an application for mobile devices aimed at re-educating and monitoring the learning of words by dyslexic. Section 4 shows the results obtained and in Section 5 we present our conclusions and future work.

2. Overview and state of art

This section presents an introduction to dyslexia as well as related work on technical materials developed to assist dyslexics.

2.1. Dyslexia

The word dyslexia comes from two Greek words: “dys”, which means “difficulty”, and “lexis”, which refers to “language or words”. This is a type of learning disability, a language processing disorder, and this term is used when people have difficulty in learning to read and write, although it is not associated with a low level of intelligence.

As research in this area has developed, the term itself, the definition and the criteria used to classify it, have shown a great diversity of opinions.

Many definitions have emerged over time as a result of various research methods. However, one that has been widely accepted by the scientific community has been proposed by the World Federation of Neurology, in Cruz [3], and by The International Dyslexia Association [4], defining dyslexia as a language learning disorder, regardless of the intellectual capacities of the dyslexic and that endures over time.

The causes of dyslexia do not generate consensus among the scientific community, but anatomical and brain imagery studies show differences in the way the brain of a person with dyslexia develops and functions. Dyslexia

can be a neurological condition caused by a different wiring of the brain, and recent studies have been converging on its genetic and neurobiological origin and on its underlying cognitive processes [5].

There are different versions of dyslexia classification and subdivision. The internationally accepted classification distinguishes acquired dyslexia from developmental (or evolutional) dyslexia. Acquired dyslexia is the provoked dyslexia, i.e. it refers to individuals who were competent readers but, because of brain injury, lost this ability. Evolutional or developmental dyslexia refers to dyslexics who have difficulty in initial reading acquisition.

A dyslexic person has difficulty in associating the graphic symbols and letters with their corresponding sounds, and cannot organize them mentally in a correct sequence. According to Hennigh [6], some common features of dyslexics are: reversal of letters in reading and writing; omission of words while reading and writing; difficulty in converting letters into sounds and words; difficulty in using sounds to create words; difficulty in recovering from memory sounds and letters; difficulty in learning the meaning of sounds and letters. Fonseca [7] adds some other behavioral features and refers problems in the following areas: lateralization and right-left orientation; notion of the body; space and time orientation; spatial representation; coordination of movements; memory; graphics; and oral expression.

These problems affect dyslexics' self-esteem, making them sometimes feel less intelligent and less capable than they really are. However, most people with dyslexia have extraordinary thinking capabilities and can be successful, as long as they are able to overcome their difficulties. Some researchers believe that dyslexic people are even more likely to be successful given the initial effort to find alternative ways of learning that stimulates creativity. We have several examples of dyslexic celebrities who stood out throughout history [8], for instance Albert Einstein, Thomas Edison, Charles Darwin and Alexander Graham Bell (in science), Agatha Christie (in literature), Pablo Picasso (in painting), Steven Spielberg and Walt Disney (in cinema), Henry Ford (in business) and Winston Churchill (in politics), among others in several areas.

Hennigh [6] suggests teachers can adopt some strategies to support a student with dyslexia, namely: create a stimulating and child-centered working environment; adjust the instruction to the child using alternative methods of instruction; establish personal, academic and family goals; stimulate initiative, self-learning and autonomy; adapt and evaluate the activities; value the learner's success, not his/her failure; diversify strategies; divide an activity in sub-activities; assess each child's qualities and skills; use pictures to aid reading comprehension; use diverse texts, with rhythm and repetition.

According to the International Dyslexia Association [9], overcoming dyslexia, and other learning difficulties, can be achieved through multisensory re-education, which involves the use of visual, auditory, and kinesthetic-tactile pathways simultaneously in order to enhance memory and written language learning. This program for dyslexia intervention has underpinned the idea that dyslexics have to look at the letters, vocalize their sounds and use language skills to access the meaning of words. Teles [5] also suggests that multisensory, systematic and cumulative methods are the most effective intervention. However, the implementation of these or other methods must take into account that the instruction must be constant and reinforced so that they can be internalized and do not fade away.

For people with dyslexia, the ability to read and understand text can be affected by the way in which text has been written and produced. The following are simple recommendations to help ensure that materials are dyslexia friendly [10], [11], [12]:

- Font Style: for dyslexics reading is a complex task. To reduce these difficulties text fonts have been developed in an attempt to maximize the readability of the letters on the part of dyslexics so as to make the printing of letters clearer and more precise. Examples are: OpenDyslexic, Dyslexie, Lexia Readable, Sylexiad e Read Regular. However, Rello & Yates [13] analyzed 12 types of different fonts in a sample of 48 individuals with dyslexia. Results showed that the font types Helvetica, Courier, Arial, Verdana and Computer Modern Unicode were the ones with greater impact on reading performance.
- Formatting: use a minimum of 12pt or 14pt font size with dark colored text (avoid green and red/pink); lower case letters and avoid unnecessary use of capitals; important piece of text should be highlighted (bold text) or colored in a box; avoid underlining and italics as these tend to make the text appear to run together; do not start sentences at the end of the line and avoid narrow columns (as used in newspapers); use at least 1.5 line spaces between lines of text keep text aligned left and don't use hyphenation.

- Writing Style: keep sentences and paragraphs short (15-20 words), simple and as concise as possible; give clear instructions, and avoid lengthy explanations and use short words and terms; break text into short readable units; use bullet points and numbers rather than long passages of prose.
- Layout: keep design simple; use plain background and avoid white or graphics backgrounds which can make text harder to read; keep essential information grouped together, such as the time, date and place of an event; include useful pictures, photos, tables and graphics to improve understanding; flow charts can help to explain procedures; provide users the possibility to customize the material to suit their needs, e.g. background color, font size, font style.

2.2. Dyslexic re-education through games for mobile devices

Games provide an individualized teaching and learning environment, which may aid in the development of memory, visual perception, auditory ability, language, reasoning, time and space orientation, and motor coordination. In this context, the games can be powerful teaching tools in order to increase the knowledge of young people and consequently improve their self-esteem, if used with pre-defined objectives.

Ball & McCormack [10] argue that developments in computers and assistive technology provide significant essential and help to students with dyslexia.

Recently, mobile projects specialized in dyslexic re-education have emerged. Examples are Graphogame (www.graphogame.org) and Dyseggxia (www.dyseggxia.com) that we introduce next.

Graphogame, designed for personal computers and with a demo version adapted for Android in January 2015, is a game that aids children learning to read in their local language with the help of technology built with the know-how of recognized experts of reading acquisition. Originally developed in Finland, in the University of Jyväskylä, in collaboration with the Niilo Mäki Institute, it employs algorithms that analyze a child's performance and constantly adjust the difficulty of the content so that the challenge matches the learner's ability. They are working in various language versions that will be made available from the year 2015 onward.

Dyseggxia was developed in 2012 by Cookie Cloud, a Barcelona-based team. It is a mobile game with word exercises that help children with dyslexia to improve spelling skills. It has been designed according to word frequency in Spanish texts, word length and the number of similar words. It is divided into three levels: easy, medium and hard. Each level contains several exercises organized in 5 types: insertion, omission, substitution, derivation and sentence [14]. The game is available for free both on iOS and Android.

A recent study was also conducted in the University of the Aegean (Greece) [15]. It is directed to the English language, with the goal to design a mobile application for Windows operating system, named EasyLexia, in collaboration with students, which could potentially decrease their learning difficulties.

2.3. Conclusion

Research continues with the goal of finding a definite definition and the determination of the cause(s) for dyslexia. However, there is a general agreement about the intervention time: the sooner the better. Although the difficulties in reading, with regard to dyslexia, have no straightforward solution, they can be alleviated through early intervention, using different strategies, methods and techniques, and supervised by various experts such as teachers, special education technicians, speech therapists and psychologists who help those with this disorder to overcome their difficulties and have a normal life.

Reading skills are essential for success in school, work and society. Early intervention is the most effective way of helping dyslexics; however intervention can be made at any time thus minimizing feelings of exclusion, rejection, harassment, abandonment, hostility and failure [7].

Being a learning disability, dyslexia is a lifelong condition. It is not a disease and it has no cure so far, but it is possible to minimize its effects through several age-appropriate dyslexic re-education programs, as we will propose in the next section.

3. Proposed Approach

In this work we propose a prototype of a mobile application, aimed at re-educating and monitoring the learning by dyslexics. We will now present the approach followed before detailing the subsequent development.

Some exercises are recommended [16] to improve word learning: identify and break words into syllables; read multisyllabic words by blending the parts together; recognize irregular words that do not follow predictable patterns; understand the different ways in which words relate to each other (example: trans, transfer, transform, transition); break words into parts, combine word parts to create words basing on their roots, or other features; use a structural analysis to decode unknown words; know meanings of common prefixes, suffixes, inflectional endings and roots;

On the other hand, Shaywitz [17] states that the better the dyslexics can decode the words, more accurate their reading is, because knowing their meaning helps decode them and thus improves the understanding of what they read. In this process, rhymes are important because they make dyslexics aware that words may be subdivided, developing the perception that words have parts. Syllables are the largest sound units that make up the word, hence it is important to master the ability to divide a word into the sounds that compose it (segmentation) and combine the sounds that form words (combination). However, this study adds that there is no formula to teach words and, as a result, any experience is a learning opportunity [17].

Based on the above recommendations this work proposes and implements a game of words to be used on mobile devices. The words used in this proposal should follow the frequency in the specific target language. In our case, we use the Portuguese language. Hence, words were selected based on the frequency of their occurrence in Portuguese language, obtained through two studies:

- The list of CETEMPúblico, produced by Linguateca [18]. The CETEMPúblico is probably the largest European Portuguese corpus list and consists of the electronic editions of the daily newspaper *Público* between 1991 and 1998, from which about 180 million words were collected, used as the basis to create an ordered list of the frequency of words in the Portuguese language.
- Study of the Frequencies in Portuguese [19], based on 141 texts from 47 authors and obtained 2.400.295 words. With this data the most frequent 2-grams, 3-grams, initial letters and final letters were obtained.

3.1. Target audience

The target audience of this work are (Portuguese) dyslexic students aged between 10 and 12 years. The rationale behind this proposal has several parts:

- Most of these students already have access to a mobile device that enables them to do the proposed activities;
- This age group has more vocabulary than younger children;
- Multisensory method is more suitable for young people who already have a history of school failure [20];
- From 9-years-old on, time and effort put in re-education increases exponentially, hence it is important to create other interactive and motivating "training" tools [21].
- This way, we will try minimize some effects that occurs after the age of 12-years-old, such as reading slowly and without fluency; misreading words; difficulty with reading rates; avoidance of reading tasks; not completing class work; slowness in answering questions; poor memorisation skills; mispronunciation or misuse of words; problems recalling the names of some words or objects; more difficulty in language-based subjects [22].

Additionally, a control group will be established, consisting of users with no diagnosed dyslexia, with similar age and attending the same school (and preferably the same class).

3.2. Application Development

The application was implemented for Android. This choice was based on the fact that most young people have a mobile device equipped with this operating system. According to the International Data Corporation [23], in 2014 the Android system was a market leader, being present in 82% of smartphone devices sold during this period, being expected that by 2018 the market share remains similar. Additionally, there is still the price factor: if a dyslexic person does not have the equipment available, the financial burden of buying an Android device is much lower than an Apple device, for example.

The game was built around the theme of pirates and for its implementation we used graphics freely available from the site freepik.com. The activities were gamified to attract users to use mobile devices as a complement in dyslexia re-education. The game consists of activities related to words' structure. Our proposal includes a set of exercises aiming at identifying:

- The beginning of words;
- Rhymes (and therefore the end of words);
- Sequences of letters in the words;
- Syllabic structure of words.

Each of the four exercises consists of a question and a number answers (words) that is randomly obtained from a local data file (CSV - Comma-Separated Values). Each exercise starts with a question and N answer options. Half of the answers are correct and the other half incorrect, and the score will be +1 and -1 respectively. From here, the difficulty level (quantity of answers) is set according to the performance of the player: the first trial of each exercise has always 4 answers, however from here the amount of answers can vary between 4, 6 and 8 depending on the score that the player obtained in the previous round. Each activity is composed of 5 rounds, and if the player does not miss any answer can achieve the maximum score of 17 points (2+3+4+4+4).

The fact that young dyslexics present low self-esteem was also considered, therefore the exposure to failure was minimized, so the player never "loses the game" and has always the opportunity to select all the correct answer, moving into the next question. Depending on the selected answer:

- A correspondent sound is emitted and changes the response image;
- For the correct answer there is a score of 1 and for the incorrect -1;
- For the player to follow his/her performance, there is an image that changes according to the score, showing the number of coins that he/she has in the treasure chest;
- The question ends when all the correct answers are selected and moves to the next;
- When the exercise ends, the user is informed about the time spent, coins obtained and the percentage of correct answers obtained.

Fig. 1. Application Screenshots.

After selecting all correct answers for each question, a set of information is saved in a local data file that can be used for monitoring by the re-education expert accompanying the dyslexic. This data include: device id, date, time, question, correct answers randomized, incorrect answers randomized, words (answers) selected by the player, total time spent in that question, average time average time spent between each tap, time for each tap and score.

4. Results

For this evaluation study, 8 children attending the 5th grade participated: 4 are dyslexics' and the other 4 are regular students. At this stage, we decided on a reduced sample, to check the usability, functionality and the relevance of the application. Some data of dyslexic's participants are presented in Table 1. They tested the application for a week, on separate days, with four rounds for fifteen minutes each. In their first contact with the application, they interacted easily with the interface using all the functionalities with dexterity, thus showing its usability.

Table 1. Dyslexic Participants.

Children	Gender	Age	Years of dyslexic rehabilitation by a specialist
Dyslexic 1	Male	10	2
Dyslexic 2	Male	11	5
Dyslexic 3	Male	12	3
Dyslexic 4	Male	10	2

They understood all the questions raised and had no trouble reading the answers, i.e. the layout and the text information is in agreement with the standards specified in the creation of materials for dyslexics. Then, we collected the data and summarized the performance for each group in the following table.

Table 2. Results obtained by **dyslexic (D)** and **control group (CG)** in each exercise.

	Beginning		Rhymes		Sequences		Syllabic	
	D	CG	D	CG	D	CG	D	CG
Time (sec) - *Average*	36	45	37	40	64	61	49	56
Time (sec) - *Standard Deviation*	8	20	16	16	23	27	18	25
Time (sec) - *Minimum*	25	23	19	16	32	27	15	22
Time (sec) - *Maximum*	48	97	74	75	103	96	67	98
Score - *Average*	16	16	14	15	12	9	8	8
Score - *Standard Deviation*	3	1	3	3	5	5	4	3
Score percentage - *Average*	94%	94%	82%	88%	71%	53%	47%	47%
Score - *Minimum*	8	14	7	6	5	2	3	2
Score - *Maximum*	17	17	17	17	17	17	13	13

The results were unexpected: dyslexics, overall, obtained similar, and sometimes better results than the control group. The explanation may be the fact that dyslexics have started an adequate early intervention. This results show us that:

- In the execution of each exercise, both groups had close average times;
- The exercises with longer duration were the Sequences and the Syllabic, without which this has translated in a better final performance. Those were the exercises where both groups had the worst performance. Yet it was also where they obtained the minimum scores;
- All participants have achieved the top score in the Beginning, Rhymes and Sequences exercises;
- The Syllables activity had the worst performances, with results under 50%;
- There was a major difference of the dispersion values, the time obtained in the course of the beginning of words. It was also found that the dyslexics had more difficulties in identifying the sequence of letters *est*. On the other hand, the control group had more difficulties in identifying words with the syllable *ma*.

5. Conclusion and Future Work

The huge growth in mobile technologies allowed for the creation of numerous new learning solutions that can be adapted for specialized education, individualized and adapted to the rhythm of learning of each student. For teachers or specialized monitors, these technologies are also a great added value, because they quickly collect, synthesize and analyze huge amounts of data, and swiftly provide feedback on the performance achieved by the student.

Taking advantage of these facts, this study sought to combine this technology with learning by creating an application for the Android operating system with the goal of helping the dyslexic student re-education that have Portuguese as their mother language.

As the results demonstrated, the use of technology was shown suitable to their needs, allowing dyslexics to achieve similar results to regular readers. However, this application, or any other, cannot represent a complete solution for dyslexic re-education: it may just be one more of the resources.

We will pursue this project by implementing various improvements and additional functions, to follow the indications to develop and implement the multisensory method, by implement memory and sound exercises, for example. Additionally, we also intend to extend the scope of the study, increasing the time period, the number of participants to obtain more conclusive results.

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