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MADRIGALE: A MULTIMEDIA APPLICATION FOR DYSLEXIA AND READING IMPROVEMENT GAMIFYING LEARNING EXPERIENCE

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ABSTRACT

In modern society about 10% of children experience difficulty in learning to read. They suffer from a neurodevelopmental disorder called dyslexia. Scientific research has shown that the ability to play action video games improves reading skills of dyslexic children. MADRIGALE research aims at designing and implementing an educational action game oriented to promote, through forms of engaging and motivating interaction, phonological training and visuo-spatial attention in dyslexic subjects aged between 7 and 9.

Index Terms— dyslexia; visuo-spatial attention; phonological processing; music action games

I. INTRODUCTION

In Italy, the Law no.170 - 8 October 2010 recognizes dyslexia, dysgraphia, dyscalculia and the dysorthography as learning disabilities, referred to as *DSA* (*Specific Learning Disorders - Specific Learning Disabilities*). For the purposes of this act, the term *dyslexia* indicates a "specific disorder that is manifested by a difficulty in learning to read, especially in the decipherment of linguistic signs, or in the correctness and speed of reading". Thanks to this law, methodologies, tools and teaching aids for dyslexia become a topic of great interest in educational research.

Studies conducted over the years demonstrate that the difficulties in learning to read and write do not have pathological character, but they represent an individual variant that hinders the acquisition and development of certain skills [1]. These obstacles can be related to *visual and visuo-spatial processing* [2], *hearing level processing* [3], *phonological processing* [4], and *meta-phonological processing* [5].

The identification of instructional strategies that involve this particular aspect is an arduous task and the outcome is uncertain. In fact advances in phonological processing do not automatically imply an improvement of reading skills [6]. Reading requires the mastery of a long chain of skills, including the management of attention. Letters must be selected from a set of other graphemes [7] through a quick orientation of visual attention [8] before the application of the correct phoneme-grapheme integration [9].

Although the cognitive processes underlying the enhancement of reading skills are not completely clear to scientific investigation yet [10] it is still possible to "mitigate and restrict the functional consequences of the disorder through specific educational interventions" [11]. Scientific literature suggests to foster the automation of psycholinguistic processes of conversion among oral strings and orthographic strings through: i) exercises structured to facilitate the reading of isolated words as well as words embedded in a given context, ii) kinaesthetic and rhythmic activities, iii) activities to enhance visuo-spatial attention skills, iv) exercises to learn the conversion rules among graphemes and phonemes, and v) repeated readings with adaptations and subsidies (text-to-speech, tutors, audio recordings) [12]–[21].

Our research aims at designing and implementing an educational action game oriented to encourage, through forms of engaging and motivating interaction, the acquisition and development of reading skills in dyslexic subjects aged between 7 and 9.

II. ACTION GAMES AND READING SKILLS

The visuo-spatial attention plays a key role in the acquisition of reading skills. Scientific research has shown that the ability to play action video games - not directly related to reading or to phonological training - dramatically improves reading skills of dyslexic children [20]. The characteristics that define an action video game are: a high degree of game speed, a high degree of perceptual, cognitive and motor load, temporal and spatial unpredictability, and the occurrence of specific events away from the center of the screen [22], [23].

Researchers tested the attentional, phonological and reading skills in two groups of dyslexic children, matched for age and severity of the disorder, before and after the use of two types of game, action and non-action, in 9 daily meetings of 80 minutes. In particular, the group who used the action video game improved reading skills more than they did in 8760 hours of spontaneous development and with a higher or

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equivalent degree to that obtained with traditional treatments [24].

Also the attention skills are increased by a treatment with action video games. Having to hit a moving peripheral target involves: i) an ability of perception of the context, and then ii) a rapid attention to detail that helps dyslexic children much more than a reading exercise. Thanks to video games, dyslexic children have learned to steer and focus in a more efficient way their attention in order to extract the relevant information of a written word, reducing the excessive side interference they seem to suffer from [20].

The individual variations detected in visuo-spatial attention and cross-modal functions explain about 50% of the variance relative to improvements in reading, after clustering by age, IQ and changes in phonological skills. Another recently published study [25] confirmed that action games can help people who suffer from dyslexia to improve their ability to read and write. Action games are able to stimulate dyslexic individuals to better integrate multi-sensory impulses.

The survey involved a group of dyslexic and non-dyslexic participants in a series of video games requiring players to press a few buttons in response to different inputs, sounds and visual effects. Dyslexics, however, has been slower than non-dyslexics in pressing the button when switching from a visual stimulus to an auditory one. This demonstrates a greater difficulty in shifting attention from one sensory channel to another, particularly when the task prompted to move from an image to a sound. According to this experiment, the phenomenon could be at the root of the problems that dyslexics encounter in reading. If confirmed, the findings could now lead the way to new strategies to improve their ability to learn the written language.

In traditional approaches the alphabetic letters are presented first visually and then aurally. Current research reveals that dyslexic people can learn associations among letters and sounds faster than listening to the sound alone and then observing the corresponding word. Traditional approaches to reading do exactly the opposite. These results demonstrate that action video games involving the training of more sensory abilities at the same time could be a great gym for patients with dyslexia.

With the right practice, in addition, dyslexics may enhance their ability to integrate multisensory stimuli, improving simultaneously also the easiness of understanding written words. Training dyslexics to quickly move the focus from visual stimuli to hearing, as happens when you play a video game, could help their ability to read and write. The possible use of video games to increase attentional skills could be useful for populations of children and adolescents with dyslexia, more difficult to treat with methods focused on increasing the reading skills through repetition. Since the latter method is very exhausting for the child, its adoption frequently caused drop-out [20].

Referring to the multisensory learning experience, "a combination of music and linguistic theory can produce a program that successfully re-mediates students with dyslexia". Besides, it is scientifically proven that "training in music is an effective additional strategy for helping children with reading difficulties" [26]. "Rhythm-based training fosters children's reading comprehension, reading accuracy and reading rate" [27].

Even if there are many scientific contributions that emphasize the benefits of sound even within the language, an effective modeling of how the sound and game experience can be integrated with linguistic training programs does not emerge with equal strength and clarity. In order to overcome this lack, our research aims at designing and developing an action game able to promote phonological training and to nurture the visuo-spatial attention in dislexic children.

III. INTERACTION DESIGN: EDUCATIONAL AND METHODOLOGICAL GUIDELINES

In the awareness that "effectiveness of game based-training is thoroughly dependent on the processing demands inherent to the exact game experience" [28], we have to itemize some functional considerations that guided the choice and design of game tasks, described in the next section.

III-A. Phonological Training

With regard to the phonological training, we need to specify that currently the game is designed for the Italian language. Needless to say, "the reading process is different for different orthographies" [29].

Katz has synthetically described the relationship between morphology and phonology as follows: "The attempt to make an efficient match between the written form, on the one hand, and morphology and phonology, on the other, typically determines whether the orthography chosen is a syllabary, a syllabary-cum-logography, or an alphabet. Further, within the group of alphabetic orthographies itself, there are varying degrees of dependence on the strict alphabetic principle: the range of correspondence between grapheme and phoneme varies both in consistency and completeness. The degree of this dependence is to some extent a function of a language's characteristic phonology and morphology, just as was the choice of the kind of orthography itself" [29].

According to Katz, the Italian writing system is *shallow* [29]: "It has highly consistent spellingsound correspondences" [28]. The *shallowness* causes that naming latencies are linearly related to length in letters [30]. "Latencies decrease as children gain skill in computing pronunciations over larger groups of letters. Italian dyslexics have not made this shift; like younger normal readers, they read aloud slowly but relatively accurately" [29]. In other words, the shallowness implies that an insufficient phonological word analysis does not automatically translate, in the dyslexic subjects, into a high number of errors, but rather in an

increase of the slowness of reading at the expense of text comprehension. "In languages with *loose* relationships between graphemes and phonemes (e.g., English), when the phonological analysis of words is insufficient, a variety of errors is produced. In languages with considerably more regular graphemephoneme correspondence (e.g., Italian), the number of errors may be small since phonological reading is generally correct, and the most conspicuous symptom is slowness in reading" [30]. Bavelier and colleagues summarize effectively: "Performance in reading aloud is only weakly related to comprehension in shallow orthographies, for which it is possible to read aloud quickly and accurately with little or no comprehension" [28].

The implementation proposed below starts from these concepts. For instance, the game tasks require a higher and higher promptness in user's reactions to sound stimuli.

III-B. Visuo-spatial Attention Training

With regard to visuo-spatial attention training, scientific research has confirmed that deficits related to visuo-spatial attention are among the main expressions of dyslexia [9], [24], [31]. "Attentional dysfunction is an important core deficit in dyslexic individuals. Letters must be precisely selected from among other cluttering graphemes by rapid orientation of visual attention before the correct letter-to-speech sound integration applies".

In this regard, "the cognitive processes involved in reading a written text may differ in reference to structures of different complexity, starting from the design characteristics of which consists of a letter (lines, angles, etc.)" [18]. This concept has led to a series of studies that aim at improving the process of reading in dyslexic individuals - in terms of accuracy and speed - by acting on specific parameters such as letter spacing, size and shape [17], [32], [33].

Consequently, the game uses a font that facilitates the process of reading in dyslexics, called DFONT and developed at the Department of Human, Philosophical and Educational Sciences of the University of Salerno. Currently such a font is made of 102 glyphs, including letters (uppercase and lowercase), numbers, accents, symbols, and punctuation.

DFONT has been released both in TTF (True Type Font) and OpenType format, consequently it is usable under Windows, Linux, Android and IOS operating systems. The key graphical feature of DFONT is related to letter shaping. A particular attention has been paid to differentiate the shape of the letters *b*, *d*, *q*, *p*, *n*, *u*, namely those letters that, in most fonts, differ as regards their form but not their spatial orientation, being often confused by dyslexics [34]–[36].

Each letter of DFONT is also surrounded by (and centered in) a squared "cage". This particular change has been made to stem the phenomenon of crowding [37], [38] through the attempt to create a kind of visual order. This should help dyslexics to distinguish both the individual characters and the extent of each word more easily. Another parameter which has been customized is word spacing: the size of the blank character in DFONT is equal to about 3 times its equivalent in Arial. In fact scientific literature suggests that a greater spacing between words increases the readability of the text for dyslexics [39].

The effectiveness of DFONT was tested through a pilot study, using the tests of speed and accuracy of reading in the MT battery [18].

IV. GAME DESIGN AND DEVELOPMENT

In accordance with the educational principles explained above, we have designed a software prototype conceived to involve children affected by dyslexia.

The idea is providing a game interface for young users, aged 7-9 approximatively, where the association among graphical signs and their pronunciation is made explicit.

The basic goal of the game is reconstructing the right sequence of letters for the words proposed by the system. Each round is made of two distinct phases: in the first one, the system draws a word and highlights its letters on a board while pronouncing them; during the second phase, the user has to select the sequence of letters in the right order and as fast as possible.

The main area of the interface, shown in Figure1, presents a number of letters that the user has to choose in order to compose words. Each letter can be used many times. The sequence to reproduce is created letter by letter during the first phase of each round, and it may remain visible during the second phase to help the player. Images in the background are conceived to enrich the graphical interface without providing too much "noise". In fact it is known that one of the aspects to improve in dyslexics is the ability to focus attention on specific spots [24]. Finally, basic text information is provided in the upper corners to trace the current score and level.

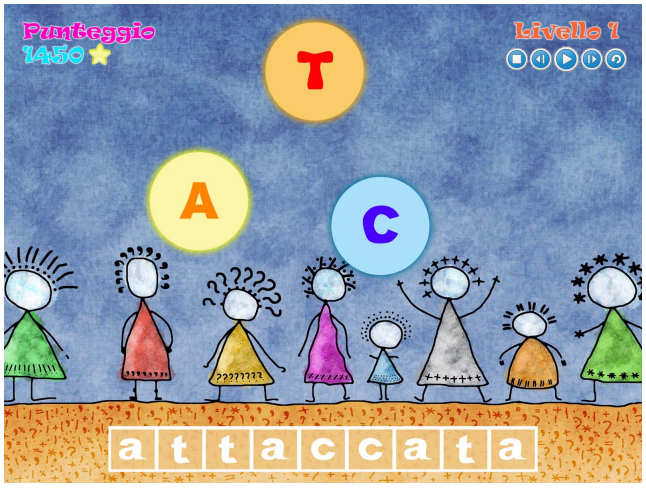

Fig. 1. The game interface.

DFONT, namely the special font described above, has been employed. From tests conducted on a number of dyslexics, this font has proved to be effective, allowing a better and easier recognition of letters.

For the game play, two aspects are fundamental. The first item is related to *skill levels*. Similarly to most games, in our proposal the player has to face increasing difficulties in order to get involved in the game play. According to in-use terminology of video gaming field, we define the concept of *level* or *stage* as a difficulty phase or given section of the game. As regards this peculiar activity, we have identified the following axes (see Figure 2):

- *Number of letters* on the board. When letters are few, the game is easier for a number of reasons, e.g. because the player can better identify the spatial position of symbols, as well as symbols are bigger and more clearly distinguishable. Please note that letters can be reused to compose words, consequently having n symbols does not imply that the system will draw only n-letter words;
- *Type of letters* on the board. A key problem for a dyslexic child is being able to focus on a graphical symbol and to recognize it against others. In this sense, some letters are clearly different (e.g. W against L) whereas other are perceived as similar (e.g. K against R);
- *Word length*. Since the game play requires to recreate a sequence of symbols, the longer the sequence the harder the player's task. Besides, repetitions in the use of letters are more likely to appear in long words.
- *Symbol layout* inside words. For a dyslexic child, some configurations - e.g. spelling words with double consonants - are harder to be recognized.
- *Symbol layout* on the board. In the graphic interface design, we tried to avoid misleading layouts, such as linear sequences. Needless to say, the way symbols are presented in the interface influences the difficulty in reconstructing sequences, above all for children who are affected by concentration problems;
- *Semantics*. For a child it is easier to associate a mental image to words such as "dog" than "asphyxia". In this sense, the mental image can be considered as a form of reinforcement in addition to other aspects of the board.

Moreover, even if the game has been originally conceived to present symbols composed by single letters, other kinds of aggregations - such as phonemes or syllables - could be introduced.

The second key aspect refers to *reinforcement* techniques. In fact, since the goal is providing a game environment to bind phonemes and graphemes, one error - or n errors - cannot merely be a failure that leads to the end of the game session. Rather, a number of reinforcements is incrementally provided to players, so that they can improve their performances. In particular:

- *Colors*. Any letter can be further distinguished through the use of colored boxes and high-contrast color combinations;
- *Intonation*. Any letter can be associated to a different pitch, so that the spoken word is in a certain sense sung letter by letter.

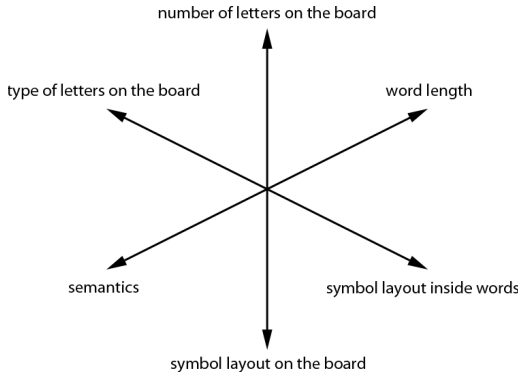

Fig. 2. Axes for increasing difficulty levels.

Even if the main requirement is reconstructing the right letter sequence, the game is designed to reward promptness as well. As regards this aspect, being quick influences both score and game progress. When the user promptly provides the right answer, he/she is considered ready to face more difficult levels.

V. CONCLUSIONS

Our research aims at defining and consolidating a theoretical and applicative framework capable of guiding the development of educational tools intended for Learning Disabilities, by using those educational approaches arising from the principles and contexts of music and game education. Here the focus is on visuo-spatial attention and phonological training.

As a result of these activities, a prototype of educational action game for dyslexics has been developed, and it is currently undergoing an *alpha testing* phase (i.e. software performance verification). A validation stage is needed to ensure that such an educational tool matches the user's needs, and that the initial specifications were right [40].

In particular, validation, from the educational standpoint, will be based on the evaluation of effectiveness and efficiency. The reading skills will be measured (ex-ante, ex-post) by referring to the most widely used and trusted test battery in Italy [18]. Tests to measure accuracy and speed in reading will be performed by using *Prove MT2*, a specific set of tests available on the marketplace.

According to Cornoldi, "the evaluation of the speed and accuracy of reading is considered to be the measure that best describes the reading skills required in various contexts of school and extra-school life" [41].

Efficacy will be assessed by comparing the changes in the parameters of reading speed and accuracy to the esti-

mated extent of natural change (i.e. without treatment) of the dyslexics. In order to be considered effective, the proposed methodology will produce "a change greater than that expected without the implementation of specific recovery procedures" [42]. For the measurement of such a natural change, the reference is the one provided by [43].

The parameter related to the efficiency will instead be calculated by relating the results of the effectiveness with the intensity and duration of treatment, once again making reference to the comparative study conducted by [42]. According to this study, the minimum duration to produce an appreciable change varies from 3 to 5 months, with an intensity of at least 5-6 hours per month.

Amplitude and stratification of the sample group are currently being finalized, in order to establish future agreements with Italian *Territorial Centers for School Inclusion* (CTI), *Territorial Support Centers* (CTS) and the National Institute of Documentation, Innovation and Educational Research (INDIRE).

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