EducationalGames: Web Application for Serious Games for Children with Dyslexia and ADHD

Letizia Angileri and Fabio Paternò

HIIS Laboratory CNR - ISTI, Pisa, Italy
{l.angileri, f.paterno }@isti.cnr.it

Abstract. Epidemiological and etiological studies have shown that, both in the clinical population and in the general population, Dyslexia co-occurs frequently with Attention and Hyperactivity Disorder. For these reasons, this work proposes a solution that aims to stimulate children suffering from both conditions in the relevant cognitive aspects, which are attention, task planning, and language processing. The solution proposed is EducationalGames, a Web application that contains two serious games: "Balloons and Letters Game" and "Robot at School game". It supports tasks which replicate daily living activities, such as preparing the backpack and reading. We present their design, a prototype implementation, and first user feedback.

Keywords: Serious games, Children with dyslexia and ADHD, User-centered design, web applications.

1 Introduction

Cognitive disorders are alterations in cognitive functions that allow the individual to interact with the world. Cognitive functions refer to multiple mental abilities, including learning, thinking, reasoning, remembering, problem solving, decision making and attention [1]. In the infant population, cognitive disorders are common because when one is born, the brain is not fully formed, it is hyperplastic and continues to structure itself from birth onwards. For external or genetic reasons, the child's brain may not function well or may not develop according to a typical line of development, and this can therefore determine atypical development of the brain that gives rise to neurodevelopmental disorders. For example, some neurodevelopmental disorders are Specific Learning Disorders (DSA) or Attention and Hyperactivity Disorder (ADHD).
One of the disorders of the DSA is dyslexia, which affects the evolutionary ability to read, write and speak, affecting the correct learning of a large percentage of the worldwide population. It is most commonly due to a difficulty in phonological processing (the appreciation of the individual sounds of spoken language), which affects the ability of an individual to speak, read, spell and, often, learn language [2].

Around 9% to 12% of the world population is affected by dyslexia [2]. While visual and auditory difficulties might cause troubles in writing and reading, the general intelligence of a person with dyslexia is not affected. Nevertheless, school failures and frustration are part of the daily routine for children and parents until dyslexia is diagnosed. Children with ADHD are hyperactive and impulsive, and exhibit difficulty concentrating, planning, and organizing their (school) work. These characteristics disturb their learning and achievement at school and hinder positive social interactions within the family and with peers.

Children with ADHD represent 3%–5% of the general population of schoolchildren under 16 years. In community samples, ADHD is more frequently diagnosed in boys than in girls (3:1) and in clinical populations even more.

Since these children may be less interested in participating in traditional therapies, serious games aim to support fun activities and therefore can be more attractive for performing interventions [3]. As play approaches help balance motivational and learning elements and integrate play goals and behavioral / cognitive challenges, they have the potential to keep these children more motivated and positively involved in therapeutic processes. In some cases, games are stimulating and give immediate reinforcement to desired behavior [4].

The proposed solution aims to stimulate children with Dyslexia and ADHD in the related cognitive aspects, which are attention, task planning and language processing. The choice is justified by the fact that previous work lack proposals to support children with comorbid ADHD and dyslexia, so we thought it would be interesting to address this aspect in an innovative solution, which should also consider the emotional aspects of the target population. On these assumptions EducationalGames was designed and built: a web application featuring two serious games for children with ADHD and dyslexia comorbidities, designed for children aged 6 to 8 years and which support multiple levels of difficulty; in particular:

• Dyslexia game, foresees three levels of play, aims to stimulate the attention and the visual-spatial channel of reading, so that users can train themselves to discriminate between mirrored or graphically similar letters.

• Game for children with ADHD, has two levels of play, stimulates sustained attention and planning (a component of executive functions).

The implemented application also received a first test with a sample of the target children. The results of the user test were encouraging: the structure of the serious games seems to be suited to their needs for fun and ease of interaction, and their cognitive stimulation, and has provided suggestions for further improvements.

2 Related Work

A recent review of the state of the art [17] found that in recent years a wide variety of technologies have been harnessed to create serious games to cognitively stimulate children. In terms of devices, the tablet is the most used technology in such studies.
Regarding the stimulated cognitive functions, regardless of the characteristics of the various technologies, the most often addressed are those relating to the cognitive aspects that may be lacking in children with ADHD and dyslexia: attention, executive functions (for example, planning skills) and language processing.
Among the solutions adopted by serious games to cognitively stimulate children, one type of approach, which seems to have a certain potential both in terms of usefulness and cognitive stimulation, is to keep motivation high through, for example, the addition of a bonus.
Regarding dyslexia, in 2014 a Spanish team created Dyseggxia a platform consisting of a series of minigames that aims to improve the spelling of children with reading disorders through targeted and playful exercises. According to the method used, the correct words are not proposed but, on the contrary, the solution of the exercises consists in correcting the wrong words [5].
Letterprins is a reading game intended for children who have already started learning to read and requires the intervention of an adult to evaluate the child's performance. It is designed to improve the reading development of children with reading disorders through a variety of reading tasks. The game asks children to pronounce letters or words, while a parent or caregiver must indicate the correctness of the child's answers. The game allows parents to assist children with their homework and record a message to be played at the end of the game.
Regarding ADHD, Fontana et al. [6] suggested Train Brain, a serious game for selective attention training. It is based on storing images in one or more contexts using colored circles. The player must also manually select the difficulty level. In this first approach, the design focuses on a gamification technique of a set of exercises that meet the training objectives. It consists in including some game elements in the exercises to motivate individuals such as: interaction with avatars and feedback. The main objective of these works is to ensure that the training meets the expectations of the experts. Furthermore, the customization does not consider the difficulty of balancing, and the users must control the training without specific guidance on their progression and training needs.
The rationale behind other works is to reuse existing casual games and try to adapt them to meet training goals. The goal is to ensure that the game not only consists of a series of exercises, but also offers users a gaming experience like that offered by classic casual games in order to improve users' motivation and their acceptance of using the game as a training tool. For example, Rijo et al. [7] have developed a game for children with attention deficit and ADHD. The game is designed by matching the learning objectives with certain elements of the game. Specifically, the player is asked to find and collect

hidden treasures such as letters, words, faces and objects to achieve training goals. They also added adaptive feedback to encourage children to listen and follow verbal directions.

Research has recently explored the positive effects of videogames on players‘ wellbeing [11][12], in term of inducing positive emotions [13], improving mood and decreasing stress, contributing to emotional stability [14], and promoting engaging, self-actualizing experiences such as psychological flow [15][16], In this perspective, the system we present in this work offers an original contribution considering not only the cognitive impairment, but also the emotional state of the children for example through acoustic and auditory feedback. These tools have been designed to avoid demotivating the children and decreasing their attention (a problematic aspect of children with ADHD), so that they perceive the exercises as a purely playful activity, albeit with the primary objective of rehabilitating the impaired function without neglecting their emotional state (particularly low self-esteem).

3 User Analysis

In order to better understand the target users and their requirements, we have used a number of techniques: interviews with a clinician and a support teacher, empathy maps and personas.

Interviews with stakeholders lasted about 45 minutes and were conducted online. We interviewed a psychologist with training in neuropsychology who deals with the rehabilitation of children with dyslexia and ADHD, and a support teacher at primary and infant school who every day finds herself instructing children with ADHD and dyslexia. The questions were designed to understand what children's approach to serious games is and what peculiarities such games should have to be useful to the target children.

After interviewing stakeholders and better delineating the characteristics that serious games should have to be useful to children with ADHD and dyslexia, two empathy maps were created corresponding to two prototypical subjects: Lucia Neri, a girl with dyslexia; Luca Rossi, a child with ADHD.

The empathy map (see example in Fig.1) was used to represent the emotions, frustrations and needs of the children towards the outside world [9]. For example, Lucia Neri, in addition to having school difficulties, also has emotional, behavioral and relational problems. She thinks it is her fault that she does poorly in school, she judges herself inferior to others in intelligence and ability.

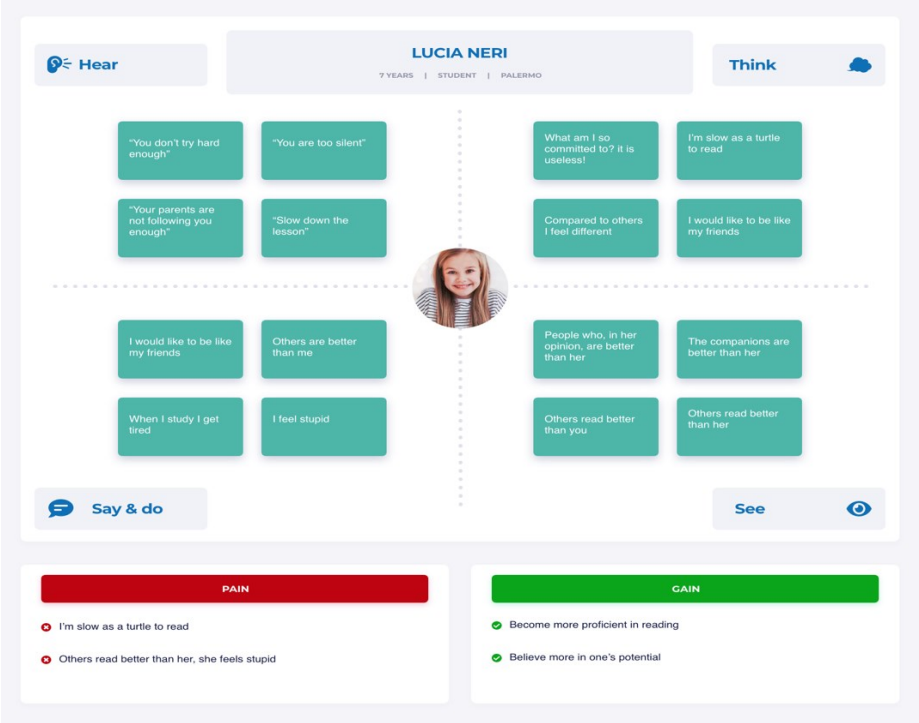

Fig. 1. Example of Empathy map created

Personas (see Fig. 2) can help raise awareness among stakeholders about users' needs [10]. While personas are made-up people, they are based on facts gathered from user research, they were created taking inspiration from films dealing with ADHD and dyslexia themes. We created them to represent the personality, motivation and relationship with technology of the two subjects of the empathy maps (Lucia and Luca). For example, Luca is a child with ADHD (see Fig. 2) and is full of energy, impulsive (he acts without considering the consequence of his actions) and inattentive. In addition, when he behaves well, his parents give him the opportunity to color and draw on the tablet in the "Coloring pages for children!" app. He would like to feel more at ease in various

circumstances, and have people around him be proud of him, rather than being continually scolded by teachers or parents.

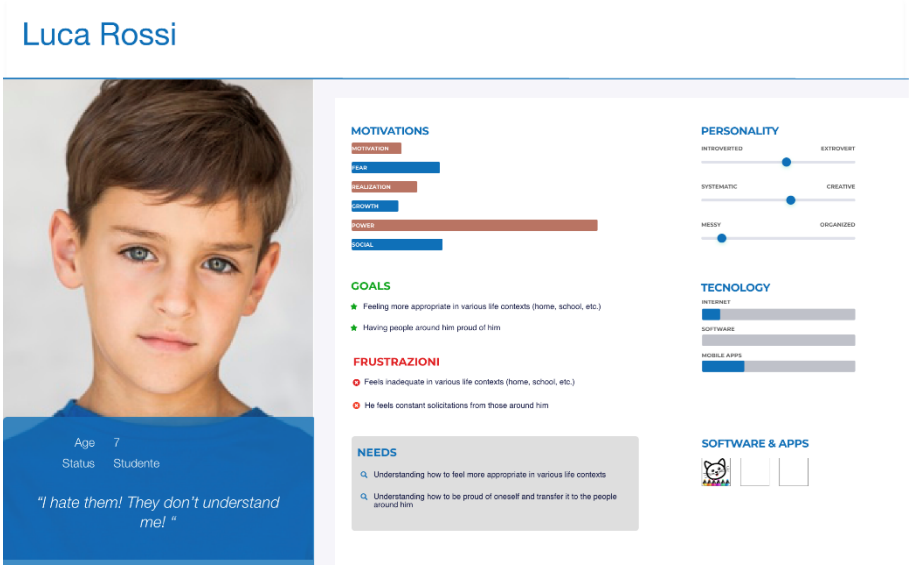

Fig. 2. Example of Personas created

The purpose of the empathy maps and personas was to create an understanding of and emotional identification with users; indeed, the results of these techniques showed that children with dyslexia and ADHD had low self-esteem.

4 Games

Before describing the design of the two serious games in detail, it is essential to emphasize that we have followed a user-centric design method. The review of related work has indicated a lack of games based on the emotional state of the child. In fact, as we have seen in the user analysis, children with ADHD and those with dyslexia have a low level of self-esteem, so the goal of the two serious games is to rehabilitate the deficient area and, at the same time, improve self-esteem while maintaining high motivation through acoustic feedback, increasing scores, level advancement, and gratification at the end of the game, which give the children the feeling that they are helping the character of the game (see Table 1). For example, the first serious game objective is to help the robot (game protagonist) to return to the ground.

In general, in the design of the individual games and the structure of the app, we considered the suggestions of a psychologist regarding the specific difficulties related to the two disorders and how the game should address them. Later, during the game design

and interface construction phases, we had further meetings with her to evaluate how specific needs were supported.

Table 1. Mapping between the characteristics of the games and the characteristics of the conditions of children with ADHD and dyslexia

Goals	Ballons and Letters game	Robot at school
Stimulate attention	- collect target elements	- select the correct letter despite changing the position of the target letter between trials
Improve self-esteem while maintaining high motivation	- acoustic feedback - leveling up - gratification at the end of the game	- acoustic feedback - increased scores - leveling up - gratification at the end of the game

4.1 Balloons and Letters Game

The "Balloons and letters" game (see Fig. 3) is a Web application developed with

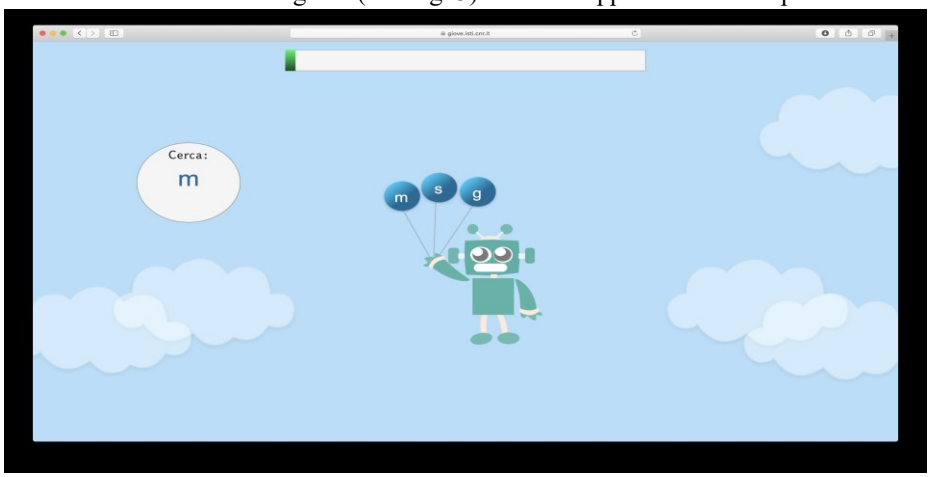

Fig. 3. Ballons and letter game

HTML5, CSS3, JavaScript and jQuery (JavaScript library). It was designed to stimulate attention and the visual-spatial channel so that the users train themselves to discriminate between mirror or graphically similar letters. The goal is to help a flying robot return safely to the ground by blowing up the balloons one at a time. Each balloon contains a

letter or grapheme with two letters. The user task is to explode the one containing the target letter or grapheme indicated at the top left of the screen. The user interacts with the game by clicking on the individual balloons. If the answer is correct, the balloon turns green and the next exercise starts, otherwise it turns red and waits for the next user interaction.
The degree of difficulty is managed both by the level and by the logic of the exercise. Each level presents five exercises, the first level shows: in the first two exercises, one target and two incorrect elements in the balloons, in the last three, the target element, one distractor (element very similar to the target) and one incorrect element. The second level presents six balloons, showing in the first two exercises a target element, a distractor and four incorrect elements, in the last three trials a target element, two distractors and three incorrect. The difficulty of the level is gradually increased as more distractors are presented in the last three exercises. The distractors are generally the mirror images of the letters of the alphabet. In the third level, where there are graphemes with two letters, the model of the five exercises within a level is applied again, the first two (a target element, a distractor and four incorrect), the last three (a target element, two distractors and three incorrect).

4.2 Robot at school game

The "Robot at school" (see Fig. 4) was developed with JavaScript (ES6), HTML5 and

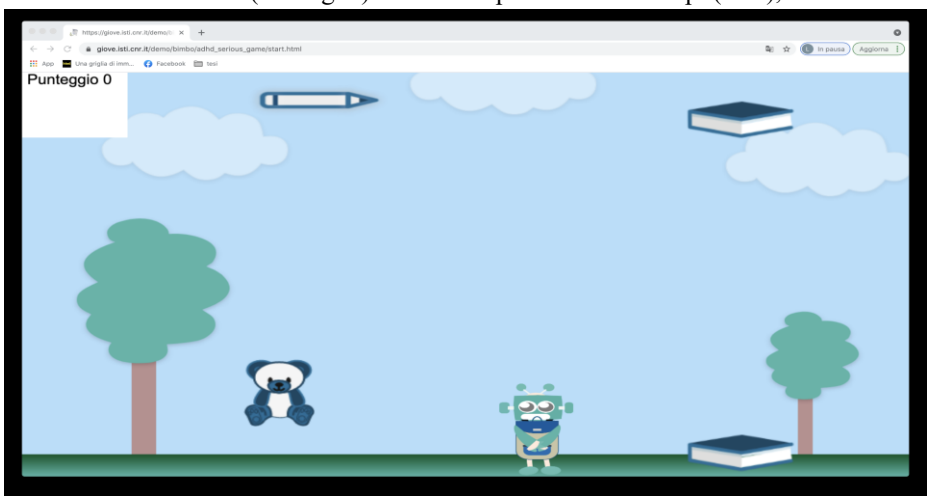

Fig. 4. Robot at school game

CSS3. It was designed to stimulate sustained attention and planning skills. As mentioned, one of the difficulties faced by children with ADHD is preparing their backpack, which is a planning task. The goal of this game is to help the robot collect the school items. The user interacts with the game through the keyboard arrows, making the

character move along the horizontal axis, while the school elements (target) and the elements of daily life (distractors) fall on the vertical axis. If the robot collects the correct element, it turns green, otherwise red. As for the execution of the game, it is designed on two levels:

- in the first level, the stimuli chosen were everyday life or school objects; among the latter, the child must find a target that will appear randomly on the screen,
- in the second level, stimuli belonging to a semantic category (school objects) were chosen and randomly descend on the screen. In this case, the difficulty is also increased within the single level, with the increase of the distractors (non-school objects also appear). In this case, the child will have to collect all the objects belonging to the semantic category "school".

5 Usability test

At the end of the implementation of the application, to understand if it could be functional or not, user tests were carried out with children with dyslexia and ADHD. The tests were performed by eight children between the ages of 6 and 8, an average of 7.25 years, three girls and five boys. This is a representative sample of the target audience, as these children have a comorbidity of ADHD and dyslexia.
All participants and the families of the children received information regarding the aims of the research and they provided signed informed consent for participating. There was no financial or other compensation for begin part of the study sample. Participants who agreed to take part in the study were reassured of the voluntary nature of their participation and their right to stop at any time.
After providing informed consent, participants were scheduled for an individual appointment in a week's time. This appointment was used to a) brief the participant about the study procedure; b) to understand the level of use of technological devices d) conduct a supervised session using two serious games and e) finally, the researchers administered the SUS (System Usability Scale) questions to the participants.
The tests were led by the educator and took place via video call. A researcher observed the children at play, taking specific notes in the field diary in relation to technical aspects of the operation and programming of the game. All incidents or problems were documented. The researchers acted merely as observers and did not interfere with the dynamics of the children and the educators.

Firstly, it was very useful to understand the level of use of technological devices, as it affects the perceived complexity in the interaction of the game. For example, Amir is a six-year old boy who often interacts with the tablet and / or smartphone and very little with the PC. He showed difficulties in using the keyboard and mouse, as they are rarely

used in his everyday life, but when he got used to them, he could not wait to start playing again. In general, users in the target audience make little use of the PC and a large use of tablets and / or smartphones.
Desktop computers are generally used mainly for web browsing, while the smartphone and / or tablet are used both for web browsing and for interactions with games. For example, Ethan (8 years old) told the clinician that he often plays with both his smartphone and computer, in fact he was one of the few who had little difficulty when interacting with the two serious games.
Later, the children were divided into two subgroups of four, which used two different versions of the games. Both the first and second test groups consisted of one 6-year-old, one 7-year-old and two 8-year-olds.

The first task was to choose the "balloons and letters" game and start it. What emerged during the tests was that younger children take longer to complete the task (see Fig. 5), probably because, apart from the disorder, children of the age of six have

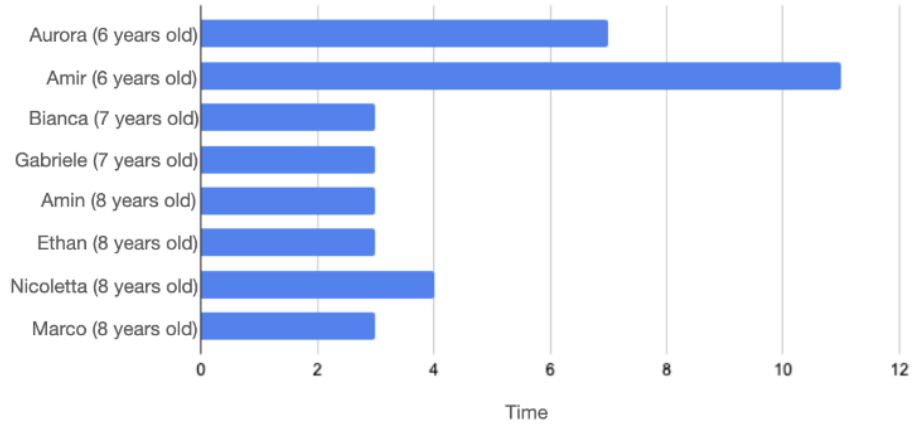

Fig. 5. Time taken for each child

difficulty reading and understanding even text in basic language. At the level of scholastic learning, and therefore of writing, the text makes the interaction with the serious game even more complex. Also, during the first task it was noted that all children had difficulty understanding the game instructions, probably because the children were anxious to play immediately. Therefore, it seems useful for the user to have feedback even while playing the game; therefore, the same game was proposed to the second subgroup with a sound feedback to each correct / wrong answer. In this way, the children in the second group asked fewer questions about the instructions and the time to complete the

activity decreased (see Fig 6). In any case, starting from this experience,

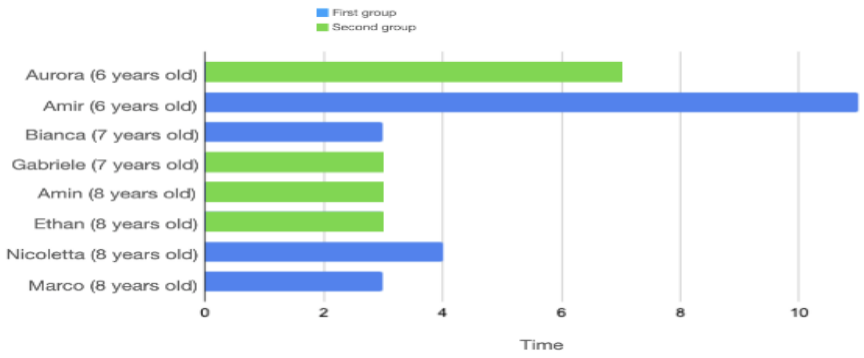

Fig. 6. Time for first and second group

we can hypothesize that the most appropriate method to remind the children of the instructions may be the addition of a visual stimulus: the system reminds the child of the rule and so he will feel guided during the execution of the task.
In addition to the difficulty in understanding the instructions, the other complexities encountered were: using the mouse, especially for children who had little experience in using the PC, understanding how to interact with the game (mouse or keyboard).
At the end of the first activity, the educator asked the participant to carry out the second activity: choose the game "robot at school" and play.
Regarding the second activity, the time variable was not relevant because the game has a time set by the system.
The first group was asked to play the game at a higher speed than the serious games tested by the second group. In fact, the first group had difficulty in correctly and quickly identifying the stimulus, while for the second group it was easier, and therefore the performance in terms of errors improved (see Fig. 7).

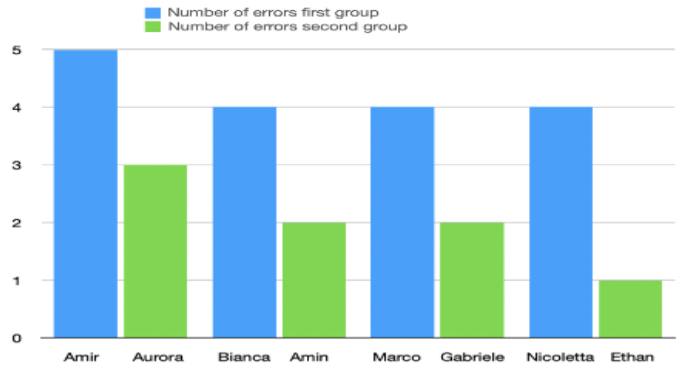

Fig. 7. Number of errors of first and second group

Finally, the SUS questionnaire [8] was used to gauge how usable participants perceived the app to be. This scale is context-specific and does not measure usability in isolation but as a product of the user interface interaction and the specific goals that users expect to accomplish with its use. The SUS questionnaire was completed for both the child and the physician. It was administered during a conversation and showed that children liked the games. When filling out the SUS item "I think I want to use this application frequently" the response was strongly positive, as 50% of the children answered 'more yes than no' and 50% 'absolutely yes'.

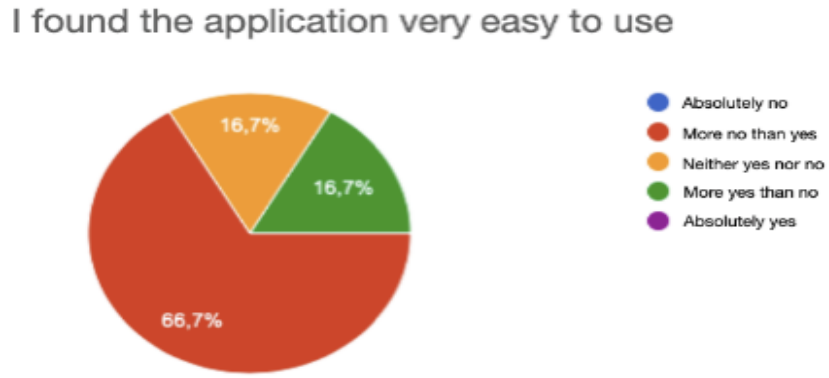

Fig. 8. Answers to one of the SUS questions

Instead, the statement "I found the application very easy to use" prompted more negative than positive feedback (see Fig. 8), as children think that having a person able to help them during the interaction with the game can help them overcome any difficulties encountered (see Fig. 9).

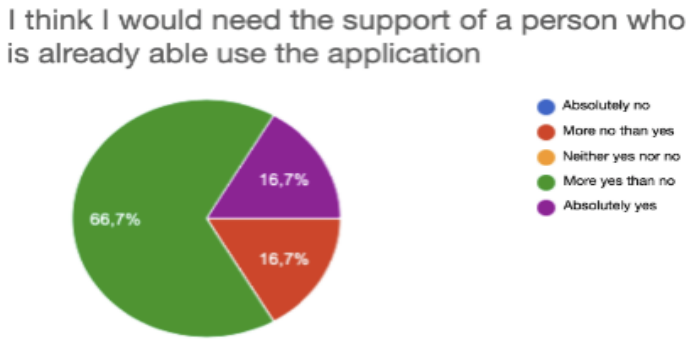

Fig. 9. Answers to one of the SUS questions

In the end, it was found that four children (Aurora, Amir, Bianca, Gabriele) gave overall modest SUS values (66, 67 and 68, 65).

The highest score was given by Ethan (the result is 90), followed by Nicoletta with 85 and finally Amin and Marco with 77.2. Hence, by improving the usability of the product and the method of explaining the instructions, it appears very likely that these two games can be used by children with ADHD and dyslexia. In any case, the average overall SUS value of the test is equal to 74.4. A positive value that can certainly be improved.

As for clinicians' input, we collected data only from one, who was the only operator involved so far, but given his daily experience of working with children with ADHD and dyslexia, his feedback was useful. In fact, according to the speech therapist, if the application were to be more usable from the point of view of explaining the rules of the games, it would be an excellent product to use, as the games in their functionality have achieved the initial purpose: the children exhibited no drops of attention and perceived the exercise as a purely playful activity, even though its primary objective was rehabilitating the impaired function.

However, according to the clinician, a similar digital tool could enrich his work, as serious games could facilitate him in the rehabilitation process, as they allow keeping the young patient's motivation high in order to keep up with therapy, and avoid making the professional exert further efforts, and make the rehabilitation process interesting, interactive and stimulating.

6 Discussion

The present study aimed to evaluate the usability of two serious games for children with dyslexia and ADHD.

From a qualitative point of view, through an observational analysis, the two serious games were appreciated by the young subjects. In fact, they did not show a decrease in attention or motivation, and the application offered easy use even when navigating between the various levels. However, during serious play it was noted that all children had a hard time understanding the game's instructions, possibly because they were eager to play right away. Therefore, it was useful for them to have feedback even while the game is running or to have a button that can help them pause the game and review the instructions.

Furthermore, an attractive design is a key factor in the quality of any activity aimed at children [21] and in order for these games to achieve positive results and impacts it is important to consider how the content is presented, what perceptual and cognitive skills the practice is brought into play and how social and emotional skills are improved [22] and children did better when it was easy for them to understand what they needed to do [17]. For such reasons in this study, after the user test, some improvements have been made, with introduction of support for interaction with touch, new level of difficulty, emotional scale at the end of the execution of the game with five facial icons ranging from sadness to happiness [18] [19], between the second and third level, the

transformation of the robot into a 'super robot', a more captivating background, addition of the button that allows you to review the instructions by pausing the game.

7 Conclusions and future work

The project presented in this paper consists in the realization of two serious games for children with dyslexia and attention disorder and hyperactivity, which places particular interest and attention to the needs and preferences of young patients. Applying a user-centered design, we have designed and developed a prototype tailored to the child so that it would be easy to use and stimulating for therapeutic purposes.
The design of the prototype posed several challenges: both the design and the implementation, through which we were able to appreciate the complexity of the world of serious games applied to rehabilitation. Serious games must be able to involve the patient so that the level of attention and motivation is maintained during the rehabilitation recovery. For these reasons, the serious games that have been designed and implemented also have the purpose of avoiding discouraging the user during the execution of the task, because demotivation can negatively affect its execution.
Even if it is not possible to do a quantitative clinical analysis of attention, from a qualitative point of view through an observational analysis, the young subjects did not show a decrease in attention or motivation and, apart from some difficulties in understanding the instructions at the beginning, the application was appreciated as it offers easy use even when navigating between the various levels.
The prototype itself has room for improvement. Potential future developments include: the addition of new levels, the ability to provide visual stimuli to the child during play, the doctor's careful monitoring of the course of therapy (including by collecting data from play sessions) and remote customization of game settings for each patient.
The project, while not yet a complete example of a serious gaming platform for the rehabilitation of children with dyslexia and ADHD, thanks to the experience derived from user-centered design and development, the valuable advice of the psychologist and the opinions of the tested children, can evolve towards developing a complete, intuitive and easy-to-use serious game platform for young subjects.

References

1. Cognitive Functioning – an overview | ScienceDirect https://www.sciencedirect.com/topics/psychology/
2. What is dyslexia - https://eda-info.eu/what-is-dyslexia/
3. Sim, McFarlane and Read. 2006. All work and no play: Measuring fun, usability, and learning in software for children, Elsevier.

4. S. Van der Oord, S. M. Bögels, and D. Peijnenburg. 2012. The effectiveness of mindfulness training for children with ADHD and mindful parenting for their parents Journal of Child and Family Studies, 21(1), 139–147.
5. Luz Rello, Clara Bayarri and Azuki Gorriz. 2013. Dyslexia Exercises on my Tablet are more Fun, Spagna.
6. E. Fontana, R.Gregorio, E.L. Colussi and A.C. De Marchi 2017. Trainbrain: a serious game for attention training, International Journal of Computer Applications 160, 4.
7. R. Rijo, P. Costa, P. Machado, D. Bastos, P. Matos , A. Silva and J. Ferrinho. 2015. A new adaptive Mysterious Bones Unearthed: Development of an Online Therapeutic serious Game for Children with Attention Deficit-hyperactivity Disorder, Elsevier Procedia Computer Science.
8. Brooke J. (1996). Sus: a @quick and dirty'usability. Usability evaluation in industry, 189.
9. Bland, D. "Agile coaching tip – What is an empathy map?" 21 April 2016. Retrieved from https://www.solutionsiq.com/resource/blog-post/what-is-an-empathy-map/
10. Interaction design foundation - https://www.interactiondesign.org/literature/ topics/personas
11. Jones CM, Scholes L, Johnson D, et al. Gaming well: links between video games and flourishing mental health. Front Psycol 2014; 5:260.
12. Granic I, Lobel A, Engels RCME. The benefits of playing video games. Am Psycol 2014; 69:66-78
13. Osmanovic S, Pecchioni L. Beyond entertainment: Motivations and outcomesof video games playing by older adults and their younger family members. Games Cult 2015; 11:1-20.
14. Russoniello CV, O'Brien K, Parks JM. The effectiveness of casual video games in improving mood and decrising stress. J Cyber Ther Rehabil 2009; 2:53-76.
15. Neri de Souza F.Science education with and through ICT: Curriculum design and questioning to promote active learning. In: Fonsecs D, Redondo E, eds. Handbook of Research on Applied E-Learning in Engineering and Architecture Education. Hershey: IGI Global; 2016; 1:133-158.
16. Cowley B, Charles D, Black M, Hickey R. Toward an understanding of flow in video games. Comput Entwrtain 2008; 6:20:1-20:27
17. Coma-Roselló T, Blasco-Serrano A C , Laparte M A G and Aguelo Arguis A Mediation criteria for interactive serious games aimed at improving learning in children with attention deficit hyperactivity disorder (ADHD). Research and Practice in Technology Enhanced Learning (2020) 15:25.
18. Diana et al. Experience-sampling methodology with a mobile device in fibromyalgia. Int. J. Telemed. Appl. 2012: 162673.
19. Garcia Palacios et al. Ecological momentary assessment for chronic pain in fibromyalgia using a smartphone: a randomized crossover study. Eur J.Pain 18, 2014, 862-872.
20. Crescenzi, L. & Grané, M. (2016). Análisis del diseño interactivo de las mejores apps educativas para niños de cero a ocho años. / An Analysis of the Interaction Design of the Best Educational Apps for Children Aged Zero to Eight. Comunicar. Vol.46, pp. 77-85.
21. Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T. and Boyle, J.M. (2012) A Systematic Literature Review of Empirical Evidence on Computer Games and Serious Games. Computers & Education, 59, 661-686.
22. Schmidt J.D.E., and De Marchi A.C.B. Usability evaluation methods for mobile serious games applied to heath: a systemic review. Univ.Access Inf.Soc. 16, 921-928.