Serious Games for Early Identification of Developmental Dyslexia

OMBRETTA GAGGI and CLAUDIO ENRICO PALAZZI, Dept. of Mathematics, Univ. of Padua, Italy
MATTEO CIMAN, Institute of Services Science - University of Geneva, Switzerland
GIORGIA GALIAZZO, Dept. of Mathematics, Univ. of Padua, Italy
SANDRO FRANCESCHINI, Developmental and Cognitive Neuroscience Lab, Dept. of General Psychology, Univ. of Padua, Italy
MILENA RUFFINO, Psychopathology Unit, Scientific Institute IRCCS Eugenio Medea, Lecco, Italy
SIMONE GORI and ANDREA FACOETTI, Developmental and Cognitive Neuroscience Lab, Dept. of General Psychology, Univ. of Padua, Italy, Child Psychopathology Unit, Scientific Institute IRCCS Eugenio Medea, Lecco, Italy

Developmental Dyslexia (DD) is a neurodevelopmental disorder affecting reading acquisition. DD cannot be diagnosed before starting the primary school; thereby, one of the main challenges is to obtain an early DD identification even during preschool years. Achieving this goal could help children at risk for DD to limit the impact of this disorder. To this aim, we have created a digital system composed of various serious games designed for predicting the risk of DD in preschoolers and potentially training specific skills impaired in this learning disability. Our set of serious games are designed to be accessible from any device, a computer with mouse and keyboard, but also a tablet with touch interface for younger children.

CCS Concepts: • **General and reference → Experimentation**; • **Software and its engineering → Interactive games;**

Additional Key Words and Phrases: Developmental dyslexia identification, serious games, mobile computing, touch interfaces

ACM Reference Format:
Ombretta Gaggi, Claudio Enrico Palazzi, Matteo Ciman, Giorgia Galiazzo, Sandro Franceschini, Milena Ruffino, Simone Gori, and Andrea Facoetti. 2017. Serious games for early identification of developmental dyslexia. Comput. Entertain. 15, 2, Article 4 (February 2017), 24 pages.
DOI: http://dx.doi.org/10.1145/2629558

Partial financial support for this work is provided by the MIUR/PRIN ALTER-NET 2009RCPLRZ and the UNIPD/PRAT Web Squared projects. This work was also partially funded with grants from the CARIPARO Foundation (Borse di Dottorato CARIPARO 2009 to S.F.; 'Progetti di Eccellenza CARIPARO' rep. no. 1873/2012 to A.F.) and the University of Padua (Assegni di Ricerca 2009 and 2011 and Senior Researcher to S.G.; Progetto di Ateneo 2009, 2011 and 2014 to A.Facoetti.).
Authors' addresses: O. Gaggi, C. E. Palazzi, and G. Galiazzo, Dept. of Mathematics, Univ. of Padua, via Trieste, 63 - 35131 Padova, Italy; emails: {gaggi, cpalazzi}@math.unipd.it, giorgiagaliazzo@gmail.com; M. Ciman, Institute of Services Science, University of Geneva, Battelle Bat. A, rt. de Drize 7, 1227 Carouge, Geneva, Switzerland; email: matteo.ciman@unige.ch; S. Franceschini, S. Gori, and A. Facoetti, Dept. of General Psychology, Univ. of Padua, via Venezia, 80 - 35131 Padova, Italy; emails: {sandro.franceschini, simone.gori, andreafacoetti}@unipd.it; M. Ruffino, Psychopathology Unit, Scientific Institute IRCCS Eugenio Medea, via Don Luigi Monza, 20 - 23842 Bosisio Parini, Lecco, Italy; email: milena.ruffino@bp.inf.it.

DOI: http://dx.doi.org/10.1145/2629558

1. INTRODUCTION

Developmental Dyslexia (DD) is a neurodevelopmental disorder identified in about 10% of the school-age children; affected children show difficulties in reading acquisition, despite normal intelligence and adequate access to conventional instruction [Gabrieli 2009]. It is often associated with undesirable outcomes, such as lower educational attainment and loss of self-confidence [Gabrieli 2009], because reading is essential for all aspects of learning, from using classic school books to the latest digital technology (e.g., e-books and smartphones).

Generally, DD is diagnosed not earlier than at the end of the first 2 years of elementary school and is characterized by reading and spelling difficulties. Detecting and treating this developmental disorder during preschool years would ensure a better chance to limit its impact and help the future reading abilities of the affected child. Recent studies demonstrated that preschool children at familial risk for DD present dorsal stream deficits before they learn to read [Kevan and Pammer 2008], as well as impairments in visual spatial attention and speech-sound segmentation [Facoetti et al. 2010]. This is crucial as visual scanning abilities, syllable awareness, and visual attention are the most important predictors of early reading and spelling [Ferretti et al. 2008; Plaza and Cohen 2007]. In this context, a 3-year longitudinal study highlighted the multi-factorial hypothesis of DD, demonstrating that visual spatial attention is causally linked to the future reading abilities independently from auditory-phonological deficits [Franceschini et al. 2012]. Moreover, stimulating both the phonological skills and the visual spatial attention can be an effective rehabilitation method in children with DD [Gabrieli 2009; Facoetti et al. 2003]. For instance, extra-large spacing between letters improves reading efficiency in dyslexic children with consistent and inconsistent orthographies [Zorzi et al. 2012], helping to focus attention on each successive letter within a word [Ronconi et al. 2014, 2015]. Playing computer games that train visual spatial and cross-modal temporal attention mechanisms can make dyslexics read better [Franceschini et al. 2013; Lyytinen 2007]. Training these skills at preschooler stage could help future reading abilities and drastically reduce the DD incidence.

Digital media has been identified as a promising tool to address DD [Beacham and Alty 2006; Magnan and Ecalle 2006]. In this context, the aim of our work is to develop a series of serious games able to identify early signs of DD risk and stimulate specific skills impaired in this learning disability even before reading acquisition [Gaggi et al. 2012; Facoetti et al. 2014]. The final goal is to train visual spatial attention, rapid speech-sound identification and discrimination, as well as visual-to-speech-sound (cross-modal) mapping, while children have fun in playing. The serious game paradigm is therefore used to keep high motivation and alert in order to reduce the therapy dropout rate and to improve neural mechanism of learning. Indeed, in a complex remediation program, it is expected that children prefer playing fun computer games than performing a boring exercise [Palazzi et al. 2010; Deponti et al. 2011; Ripamonti and Maggiorini, 2011; Roccetti et al. 2012, Gerla et al. 2013].

From a research methodology point of view, this work is a step, although a significant one, in a larger and long lasting project composed by several phases:

(a) Hypothesis formulation and demonstration of the correlation between, on the one hand, the familial risk of DD and, on the other hand, impairments in visual spatial attention and speech-sound segmentation.
(b) Hypothesis formulation and demonstration of the correlation between spatial attention and future reading capabilities.
(c) Hypothesis formulation about the effectiveness in using games for early identification of DD risk and its treatment.

(d) Development of serious games to test hypothesis (c) and evaluation of their appeal on pre-schoolers as well as of their ability to detect the risk of DD.
(e) Full scale tests with serious games developed in (d) and with off-the-shelf games for handheld consoles to evaluate their capability to reduce the risk and effects of DD.
(f) Administration of game sessions to a subgroup of children using our serious games and off-the-shelf games for 2 years.
(g) Verification after phase (f) of the accuracy in predicting the risk of DD and the ability to treat it.

Phase (a) was done in Facoetti et al. [2010], whereas (b) was done in Franceschini et al. [2012]. In this work, we describe the work carried out for phases (c) and (d). We are now organizing phase (e) involving various kindergartens in Italy, whereas phases (f) and (g) are left as future work.

Therefore, in this article, we present our serious games developed to investigate neurocognitive abilities which are impaired in children with DD. In particular, we tested the neurocognitive skills related to the future reading abilities in pre-readers; our approach aims to measure, and possibly train, these skills through games. To allow an effective treatment and develop the individual skills that will be useful to learn to read, each child needs to repeat the set of exercises (games) on a daily basis. For this reason, a crucial goal of our study is to ensure that the created games were engaging in order to transform an annoyed or bored patient into an excited player.

The remainder of this article is organized as follows. Section 2 provides an overview of previous related work. Section 3 describes the employment scenario for our games, which are presented in detail in Section 4. The system architecture and its implementation are described in Section 5. Section 6 discusses the performed user study to evaluate the applicability of our games, whereas Section 7 reports collected results on preliminary evaluation on the games' ability to early identify the DD risk. Finally, conclusions are drawn in Section 8.

2. RELATED WORKS

The *serious game* paradigm aims to engage users into an activity, which produces a common good or teaches something valuable to the player, concealing it into a game [Michael and Chen 2005]. The idea is that the user does something useful, which she/he normally would not, because she/he enjoys doing it [Roccetti et al. 2011]. If the user has fun, she/he will probably continue to play, achieving the serious goals of the game. The serious games that we consider in this work are applications that can work either on computers or mobile devices like tablets or smartphones.

There are several different applications of serious games (e.g., military, governmental, medical, education, training). When employed for military applications, serious games are used to train soldiers using virtual environments that reproduce real-world scenarios. The main scope is to prepare soldiers to the situations and obstacles that may populate the real world, to make them able to make decisions faster and safer. Serious games can be used in the governmental field to simulate the population's reaction to political decisions [Practice 2012] and in the educational field to increase learning abilities of children as well as to train employees [Zapusek 2011].

In the medical field, serious games are becoming very important, both for doctors and patients. The former can be trained to correctly execute specific procedures or be exposed to real-life experience simulations [Esteban et al. 2011], whereas the latter can make use of rehabilitative exercises hidden by games to encourage them, for instance, to perform specific upper limb movements as those proposed in Ma and Bechkoum, [2008] or to offer telerehabilitation to post-stroke patients so that they can perform the long series of exercises at home [Di Loreto and Gouaich 2011]. Furthermore, games can be tailored for particular disease groups in order to improve patients' recovery and motivation. For instance, Re-Mission is a game that helps young patients to understand and deal with cancer by employing game avatars representing the drug that destroys cells with cancer and providing a forum where patients can discuss and support each other [Kato 2010].

We are interested in serious games for children's rehabilitation as they are specifically related to our work. PlayWithEyes is a serious game for the diagnosis of amblyopia in children [De Bortoli and Gaggi 2011; Gaggi and Ciman 2015]. The authors developed a system for iPad and iPod Touch that uses a serious game to perform an orthoptic test to evaluate children visual acuity. This project has shown how children find playing a game more appealing than performing regular tests; their increased attention results in more accurate diagnosis.

Ciman et al. [2013] designed a serious game to help the rehabilitation process from CVI (Cerebral Visual Impairment). The game is able to adapt the rehabilitative exercises to each child, also following the improvements of the patient, to reduce the influence of her/his disability in future life. The system also helps doctors to perform a good assessment of a patient and to create a rehabilitation program.

It is easy to see that serious games are extremely useful for children because the game can lure players into performing with accuracy an assessment of a particular disease as well as offering rehabilitation and telerehabilitation programs that could last a long period of time. Since our system is specifically intended for pre-school children, we must pay particular attention to the interface and how this can be effective in engaging children. One interesting possibility is to use the so-called *tangible interfaces*, which use physical artifacts for accessing and manipulating information [Pittarello and Stecca 2010]. To this aim, Forlines et al. [2007] investigated the differences between mouse and direct touch input, both in terms of quantitative performance and subjective preference. The work demonstrated that touch interfaces, even if they may not lead to greater performance, especially for speed and accuracy, are preferable for other considerations like fatigue, spatial memory and simplicity. This is particularly true for children, even those called *digital native speakers*, who find touch interaction very natural, thus avoiding the need for long training sessions to learn how to interact with touch applications.

We have also found other two works that, similar to ours, describe serious games specific for children with Dyslexia. The first one is DYSL-X [van der Audenaeren et al. 2013], which integrates Dyslexia predictors in a tablet game to capture the children's attention and obtain a more accurate measurement. The authors evaluated several existing games for preschoolers to derive a set of guidelines to design an optimal tablet game for 5-year-old children; then, these guidelines were used to develop Diesel-X, a game about a robot dog, Diesel, who has to fight against a gang of criminal cats. Diesel-X contains three games, which, unlike our system, requires players to know letters. Our games make an implicit use of letters, which appear on the screen, but the children are not required to know them. Moreover, our system can be used both with a tablet and a common computer, while Diesel-X is explicitly developed only for tablets. Therefore, our games lower the requirements for players and their equipment. Furthermore, no validation is provided in literature for DYSL-X.

Letterprins [Steenbeek-Planting et al. 2013] is a reading game designed to improve the reading development of children with reading disorder through a series of reading tasks. The game asks the children to pronounce letters or words, while a parent or a caregiver has to indicate the correctness of the child's answers. The game allows parents to assist the children during the tasks and to record a message to be played at the end of the game. Unlike our system, Letterprins is not intended for pre-schoolers but for children who have already begun to learn reading and requires the intervention of an adult to evaluate the child's performance. Furthermore, unlike our system, Letterprins is solely designed for tablets, thus limiting the set of possible hardware that could be used.

3. EMPLOYMENT SCENARIOS

Before designing our games, we performed an evaluation of the different scenarios where our games will be employed; this allowed us to identify adequate devices and development technologies. In general, the initial approach with the games to assess the potential risk for DD is performed in a specific structure such as the therapy room or the school. On the other hand, when the games are used as a treatment, the child has to interact with the games for an intensive period of time, even from home.

Computers and Internet connectivity are typically present in domestic environments, but they could be missing in the therapist room or at school. Moreover, at home, the application and the device are probably going to be employed by a single child, whereas in school the available instruments will be probably shared by several children.

Different digital devices could be present in the children's homes; consequently, our games should have adequate features and a high degree of compatibility to run on different devices [Furini 2007]. To this aim, the application has to be portable over different platforms in order to let families use any device they may already have at home without the cost of purchasing a new one. As it is well known, nowadays the Web is the programmable environment that ensures the widest portability.

Summarizing the aforementioned requirements, the devised serious games have to ensure the widest portability regardless of the device (e.g., PC, tablet, smartphone) and of being played on-line or off-line [Ferretti et al. 2010]. Another crucial aspect is the age of the targeted children. It is important to note that preschool children are too young to allow a confident diagnosis with a clinical approach. At preschool age, we can evaluate only a "DD risk", which still represents an important indicator since preventive treatments could produce better results in reducing the reading disorder by leveraging on the plasticity of the brain during the first years of life [Gabrieli 2009]. Yet, an identified DD risk does not necessarily imply the future development of the disorder. Given this lack of confidence in identifying preschool children with DD potentiality and the benefits of the treatment, it may be advisable to administer the developed serious games to all preschool children.

4. DEVELOPED GAMES

In this section, we describe the most representative games we have developed to assess and treat preschoolers at risk for DD. The games are presented in the same order proposed to children during play time. Each game is designed to train specific skills linked to visual attention, typically investigated with spatial cueing procedure [Posner 1980], in which attention is engaged across locations by peripheral and rapid spatial cue. Cue stimuli are used to have the player focusing on the target, whereas distractors train perceptual noise exclusion mechanisms. The use of these stimuli affects the players' performance, especially in younger ones such as preschoolers. Our games increase the use of spatial and temporal cues with players having gaming difficulties, while the occurrence of distractors increases with more skilled players. In essence, throughout all our games we have employed the concept of *flow* to keep the player engaged [Csikszentmihalyi 1990; Koster 2013]. Any game is fun only if it provides an adequate level of challenge for the player. By adapting the game speed and the occurrence of hints and distracters, we have tried to endow our games with a dynamic balance between challenges and the player's skills.

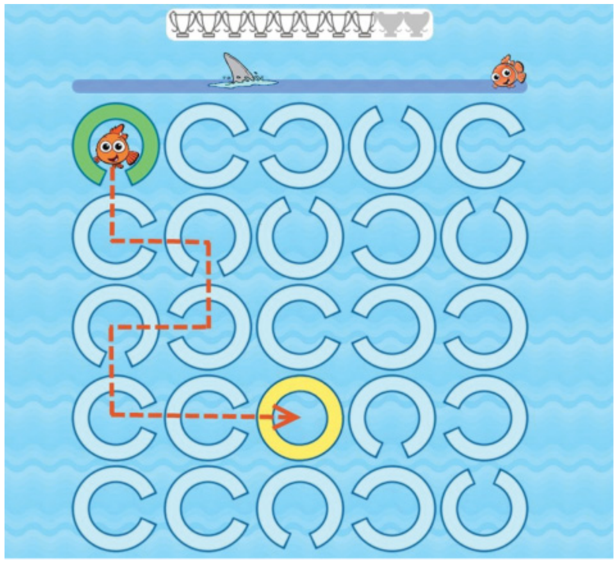

Fig. 1. Paths game.

4.1. Game #1: Paths

Paths is a game created to train the ability to rapidly discriminate among images in the central (fovea) and peripheral vision. The fovea constitutes the center of the macula region of the retina and is responsible for the sharp central vision.

Players start from the green open circle and has to reach the yellow closed circle within a pre-defined time lapse in order to win the game (see Figure 1). The player has to move from one open circle to the other based on its orientation. Each circle has an opening only on one side, giving only one direction in which the player is allowed to move into the next open circle. During the first three moves, the player is helped by a cue, a visual stimulus pointing to the right direction. The game difficulty increases according to the increasing ability of the child, gradually reducing the size of the opening in the circles, that is, a classic staircase procedure [García-Pérez 1998].

Every session consists in five matches that have to be played by the child. At the successful conclusion of the previous match, a new, more difficult path, with narrower circles' openings, will be presented. Conversely, if the path is not successfully individuated by the child, the same path is proposed again.

This game involves a serial visual search task, which implies the ability to identify visual stimuli. This process is the result of the children's ability to rapidly engage, focus, and disengage their visual attention among cluttering objects. Indeed, the crowding effect, the difficulty in the visual recognition of a target surrounded by other visual elements, plays a crucial role in the reading performance [Zorzi et al. 2012]. To successfully finish the game, the child must improve her/his ability to analyze each element by rapidly engaging/disengaging attention in central and peripheral vision.

4.2. Game #2: Local Visual Search

A Local Visual Search game is based on the documented difficulties reported in individuals with DD regarding single object identification [Franceschini et al. 2012]. This game focuses on the ability to analyze the local characteristics of a figure in order to identify its details. The figure corresponds to the entire screen and is composed of a series of objects (i.e., sea creatures) randomly arranged and repeated (see Figure 2).

Fig. 2. Local Visual Search.

The player has to identify a particular target object on the screen, which is shown prior the start of the game session.

If the player cannot recognize the target within a certain time limit, a shark, with the double function of a cue and of a virtual competitor, appears on the screen signaling the position of the searched element. If the player does not timely react to the arrival of the shark, the latter captures the target. The shark appears also after five, even non-consecutive, errors. Regardless of whether the player captures the target or is anticipated by the shark, a random letter is pronounced and appears for a short time (150ms). Besides training the subject's attention, the association between grapheme and phoneme is trained by implicit perceptual learning which was demonstrated to be effective in both visual [Sasaki et al. 2010] and auditory [Seitz et al. 2010] domains.

4.3. Game #3: Hidden Fish

Hidden Fish is a game that measures and trains the orienting mechanism of visual spatial attention typically investigated by the Posner's paradigm [Posner 1980]. In this paradigm, attention is engaged across locations by peripheral and rapid spatial cue measuring the reaction time to attended, non-attended and neutral target locations. The subject's attention is allocated on a portion of the visual field by the appearance of an informative cue (which correctly indicated 66% of the times the following target position). Faster reactions are expected when the target appears at the cued location (valid condition) rather than at uncued locations (invalid or neutral conditions).

The aim of this game is to train visual spatial attention, which has been demonstrated to predict the DD risk [Facoetti et al. 2010]. Two sequential tasks are proposed to the player. In the first one, the player must identify the target object (a fish) that appears from behind one of two stones, as shown by Figure 3(a). Target objects appear one at a time, after a valid, invalid, or neutral cue.[1] Seldom, non-target objects may appear on screen; in this case, the child has to not respond.

In the second task, the target objects appear in couples from behind four stones. One fish appears from one of the two stones positioned in the upper part of the screen,

[1]A neutral condition is characterized by a contemporary cue from both sides of the screen.

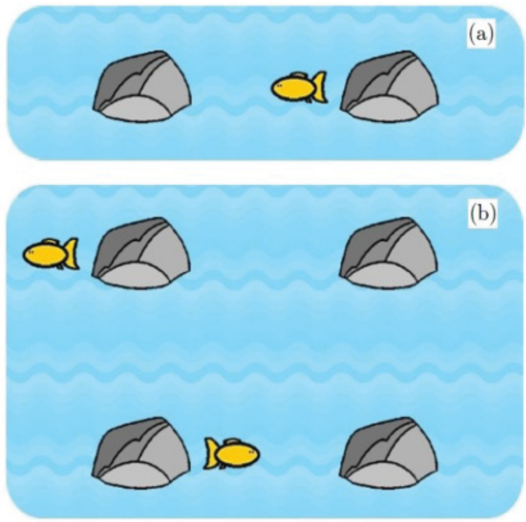

Fig. 3. Hidden Fish game: (a) with two hiding stones, (b) with four hiding stones.

whereas the other appears from one of the two stones in the lower part of the screen (Figure 3(b)). Target objects remain visible for a period of time, which goes from 2s to 6s, depending on the difficulty level achieved by the player. If the player is not quick enough to spot and touch them, they go back behind the rock from which they emerged.[2] The movements of the objects are exclusively horizontal. Each time a target object is identified, a randomly chosen letter is pronounced and appears on the screen for a short time (150ms). The aim is to implicitly train the ability to associate a grapheme to its correct phoneme as suggested by Seitz and Watanabe [2003], Sasaki et al. [2010], and Seitz et al. [2010].

A single game session includes 18 target objects and 6 non-target objects that appear on the screen. Each object has an associated cue (valid, invalid, or neutral) and a direction (left or right). As the player's ability improves, the game becomes progressively more difficult by decrementing the time between the cue and the target onset, and by using faster moving objects that remain visible for a shorter time.

4.4. Game #4: Fence Letter

We designed and implemented a game, named Fence Letter, to train the child's ability to focus on local stimuli, ignoring the global structure which is a large letter with partially dashed boundaries. The subject has to close lines in the letter, by touching the openings in the fence, before a shark swimming inside could escape (see Figure 4).

After identifying and closing all openings, the complete outline of the fence (the large letter) is highlighted and a letter-sound is played as a feedback in order to produce an implicit association grapheme-phoneme [Seitz et al. 2010; Sasaki et al. 2010]. As the player's skills improve, the difficulty level increases by adding new fishes and augmenting their speed. This process helps the development of switch attention abilities because the player has to pay attention to the movements of two or more stimuli (i.e., the fishes, the fence, and the shark), which requires both diffuse and perimeter-specific attentional focusing.

[2]The child has to touch (or to click on) only target fishes. Non-target elements must be ignored; otherwise, the player pays a penalty, losing some of the gained points.

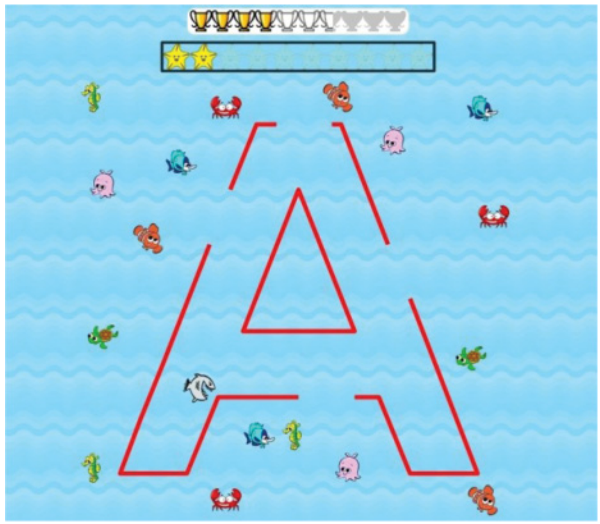

Fig. 4. Fence Letter game.

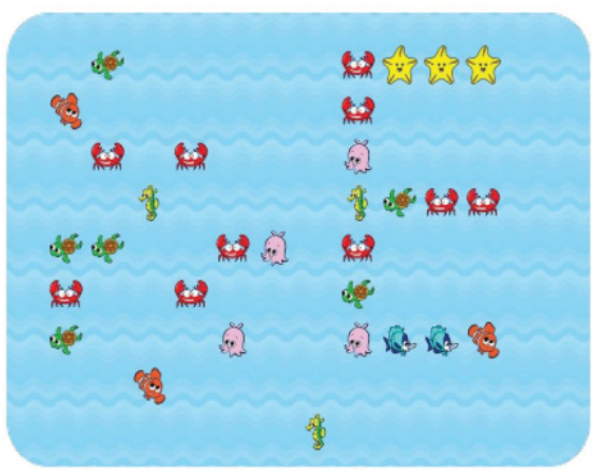

Fig. 5. Global Visual Search game.

4.5. Game #5: Global Visual Search

In the Global Visual Search game, the aim is to train global research skills, making children able to switch from a local to a global search, modulating the attentional focus sizes [Ronconi et al. 2014, 2015]. The task also includes visual analysis of graphemes. As shown by Figure 5, the player has to identify a specific shape (i.e., a capital letter) composed of a series of objects (i.e., sea creatures).

In case the player cannot recognize the target within a certain time, a shark, with the double function of a visual cue and virtual competitor, appears on the screen signaling the position of the searched element, but also trying to capture the letter in case the player does not react timely to the cue. The shark appears also after five, even nonconsecutive, errors. Each time the player or the shark identifies some of the objects that compose the capital letter, that letter is pronounced and shown on the screen for a short time (150ms).

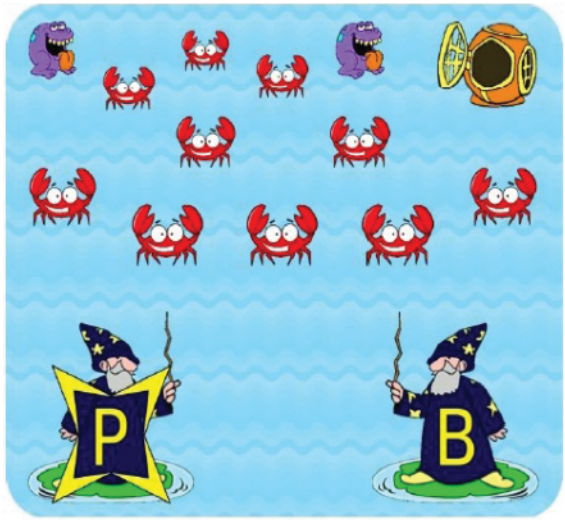

Fig. 6. Wizards game; a cue is visible on the leftmost wizard.

4.6. Game #6: Wizards

The Wizard game explores the ability to rapidly process auditory stimuli, typically impaired in children with DD [Tallal 2004]. It is also argued that a reading deficit is characterized by a deficit in categorization of the phonemes that compose words. Auditory processing is typically investigated with the Temporal Order Judgment (TOJ) task [Jaśkowski and Rusiak 2008]. In this task, the subject has to identify which of the two auditory stimuli is emitted first.

In the Wizards game, children have to discriminate coherently the first of two sounds that is rapidly presented by two wizards competing in magic (see Figure 6). Specifically, a letter is assigned to each wizard who pronounces it. The first wizard pronouncing its letter transforms some crabs into tiny monsters. The player has to indicate (through the touch screen) which wizard cast the spell by identifying the pronounced letter. If correct, then the tiny monsters are retransformed into crabs.

The two letters associated to the two wizards are chosen in pairs among those known to be hardly distinguished by dyslexics, such as, for instance, P and B. Each phoneme lasts for 150ms. The time interval between the end of the sound of a letter and the beginning of the next one (inter-stimulus interval, ISI) has a variable duration, between 200, 80, or 30ms, depending on the child's ability. Initially, the ISI is 200ms. When the child is able to complete the task, the ISI is decremented to 80ms, and then to 30ms. At the beginning of the game, beside the phoneme there is also a visual stimulus (in Figure 6, it is the yellow visual cue on the left wizard), associated with the letter in order to help the player to understand the task. The cue is deleted after half of the game session rounds.

5. SYSTEM ARCHITECTURE AND DEVELOPMENT

As anticipated in Section 3, the proposed games must be accessible everywhere, both on-line and off-line, in order to adapt to the largest number of different situations in which a user could play. Moreover, the specific target users, preschool children, require particular attention to the used interaction paradigm. Therefore, the design of the system architecture must take into account two different issues:

—the usability of each game, considering the particular target users and
—the portability of the overall system.

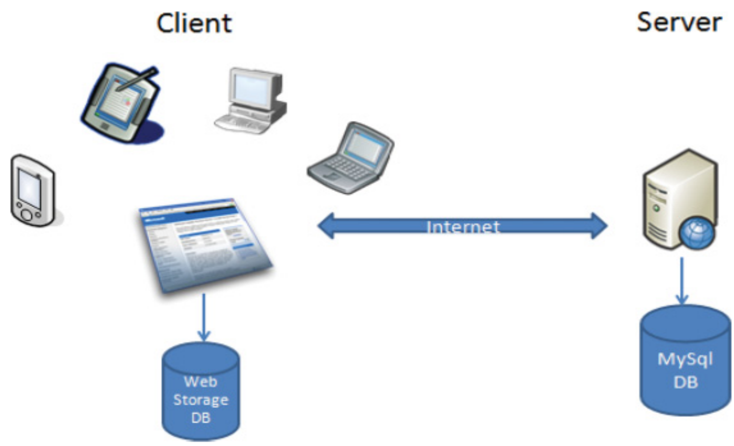

Fig. 7. Architecture of the developed system.

Some studies [De Bortoli and Gaggi 2011; Gaggi and Ciman 2015; Forlines et al. 2007] proposed the touch interfaces as a suitable interaction paradigm for very young children, even for children who are just 2 years old. Their tests showed that this interaction paradigm is very natural [Forlines et al. 2007]. Children can interact with touch screen devices (e.g., tablets) without having to learn first the use of standard peripherals such as a keyboard (preschool children do not know letters) or a mouse: they can simply touch the screen with a finger in the same way they would touch any object in a real-world experience. For this reason, touch interfaces are excellent candidates for interfaces of applications specifically targeted for children.

The data transmission system that forwards the children's measured performance to a remote database is based on a classic client-server architecture, which is depicted in Figure 7.

The server has to perform two main tasks:

—provide the games and
—collect data for each user during exercises to check the progress during the training activity.

The server is implemented on a LAMP (Linux, Apache, MySql, PHP) architecture: it collects data on a MySql database that can be queried by the administrator, or the children's psychologist, through a set of web pages that retrieve data using the PHP language.

The client side is responsible to show the games and to collect all the data about performances and answers of each child.

To address portability, all the developed games must be playable on a large set of devices, either desktop or mobile. For this reason, we implemented our software as a *Rich Internet Application (RIA)*. Each game is a web application, accessible virtually through any browser: successful tests have been conducted on Microsoft Internet Explorer,[3] Mozilla FireFox,[4] Google Chrome,[5] and Apple Safari,[6] both on the Apple and Microsoft main operating systems.

We used several HTML5 features to reach the highest portability of the system. Thanks to the `cache manifest` feature, during the first access the browser downloads all

[3]Version 9 or higher, although IE version 9 does not support to play the game off-line.
[4]Version 3.6 or higher.
[5]Version 10 or higher.
[6]Version 5 or higher.

it needs to play the game. After this first step, the games can be played even in absence of Internet connectivity (i.e., off-line), which is required later only to send the collected data to the server, after the end of the session. These data are collected on the browser using HTML5 `local storage`. Several game sessions can be played without sending data, which are sent only when the local storage is full. In the latter case, the game will be blocked until the data will be sent to the server and the local storage will consequently be emptied. In this way, this architecture reduces the network usage for communication between server and client. For similar reasons, we used `Web Storage` instead of `Web SQL Database`, since the first one is already supported by a larger set of browsers.

Even audio files are provided in different formats to support the highest number of browsers. We used both the MP3 format, supported by Chrome, Internet Explorer and Safari, and the ogg/vorbis encoding, supported also by Firefox and Opera.

To address usability, that is, the effectiveness, efficiency, and satisfaction with which specified users achieve specified *goals* in particular *environments* [ISO 9241-171: 2008] we have initially tested our system using a touch screen connected to a computer and asking a small set of children to evaluate the games. The main advantage of this testbed is the large size of the screen, which helps usability with children. However, large touch screens are neither generally available in schools nor very portable for their size, weight, and need to plug in for electricity. Therefore, a set of tests have been performed using two tablets: an Apple iPad 2 and an Android-based Asus TFT101.

These tests revealed that both the devices had initial problems in running the games as, for instance, they did not support the simultaneous playout of more than one audio file. To solve this problem, we needed two distinct applications, one specific for each platform, and a technology capable of carrying out a conversion from a web application to a native one, that is, the PhoneGap framework [Adobe Systems, 2012].

Moreover, since some children do not have the possibility to use a device with a touch interface, to improve usability for children playing using a mouse, we increased the size of the mouse's pointer to facilitate its localization.

5.1. PhoneGap

PhoneGap is a framework that allows the creation of mobile applications from web applications using web standards like HTML5, CSS3, and JavaScript. PhoneGap does not translate the code into the native language of the platform for which the application is compiled; rather it encapsulates its code together with the web engine webkit, so that it can be executed without the help of a browser. Moreover, PhoneGap provides APIs to access the device's features (e.g., accelerometer, wireless connection, media playback, notifications, storage system).

PhoneGap is a wrapper; it hence requires computational and memory resources to run the webkit engine in addition to the resources needed for the application itself. On the other hand, it has the advantage to support almost all the mobile platforms, that is, Android, iPhone OS, BlackBerry, WebOS, Symbian, WindowsPhone 7, and Bada, without requiring to know how to program on these platforms, but exploiting all the new features offered by HTML5 and CSS3. In addition, well-known JavaScript libraries, like jQuery, can be used without any problem.

Since our games have been implemented using web technologies and HTML5, PhoneGap is the perfect candidate to solve the problem of the playback of more than one audio file at the same time. Therefore, the only modification required to run our application on mobile devices is to use PhoneGap functions, instead of the HTML5 standard tags, to include soundtracks and other audio effects used as user feedback for specific actions.

5.2. Best Practice for the Interface Design

Our serious games have been developed using a 2D graphic design, where each element of the game is represented by an image that can be moved on the screen during the game, autonomously (e.g., the shark in the Fence Letter game) or as the result of the user interaction (e.g., the fish in the Paths game). Since the game can be played even on devices with lower CPU resources (e.g., a tablet), we must pay particular attention to the system performance during the development.

Using HTML5 language, images can be inserted with the tag img or drawn on the web page inside a `canvas`. A canvas is a rectangular area of an HTML page used as a container for graphics, either simple lines, polygons, etc., or even more complex elements like images.

To use an `img` tag or a `canvas` tag is an important choice, since these two options are quite different, especially for the obtained results in terms of performance. Therefore, we have defined a set of guidelines to avoid the flickering effect in the user interface when too many animation effects are used.

One of the main issues is related to the correct use of `canvas`. According to the current definition in HTML5, every time the content of a `canvas` changes, even for a minor detail, the entire element has to be redrawn. During this operation, the game suffers a temporary pause while no other operation can be performed. As soon as the size of the `canvas` increases, this waiting time increases too, dreadfully impairing the quality of the user's experience.

For this reason, it is not a good choice to encapsulate the whole game into a single `canvas`; there should usually be at least two `canvas` instances, one related to the background and one related to the elements with which the user can interact. One possible alternative would be to use libraries like EaselJS, a framework that manages the canvas and its objects in a hierarchical way and simplifies the usage and the update of canvas elements. However, since our application is not complex and does not require hierarchical management of elements, these kinds of libraries may introduce more complexity than needed.

A correct strategy to use `canvas` in each game is to consider the behavior and the logic function of each element: elements with different logic functions must be inserted in different `canvas` instances, since they typically have different behaviors. Moreover, management of more than one element with the same logic function and similar behavior can be made easier if they are contained in the same `canvas`. We note here that we do not need to insert each element into a `canvas`: if we need to move an object as a whole we can use a transition effect on a single image.

More in general, it is a best practice to use a canvas when:

—the game requires to draw lines or simple geometric figures;
—the content of the canvas does not frequently change (e.g., the set of objects composing the background);
—a set of game images is perceived by the user as a single object (e.g., the score bar).

Conversely, it is a best practice to use an img tag when:

—the picture is an element of the game that is frequently updated in position and size;
—the picture is an element with which the user must interact.

As an example, Figure 8 shows three `canvas` and two img instances for the Paths game. Each canvas is denoted by a circle with numbers 1, 2, or 3, whereas each img is denoted by a circle with letters "A" or "B".

The canvas number 1 contains information about the score. It is composed by a set of images, but perceived by the user as a single object. Similar, the second canvas contains two elements that make up the time bar; it is composed of a thick dark blue line and a fixed image on the right. Finally, `canvas` 3 builds up the background of the game.

Instead, images are used for elements whose position needs to be continuously updated. In fact, `img` A must be continuously moved to the right to show the time elapse

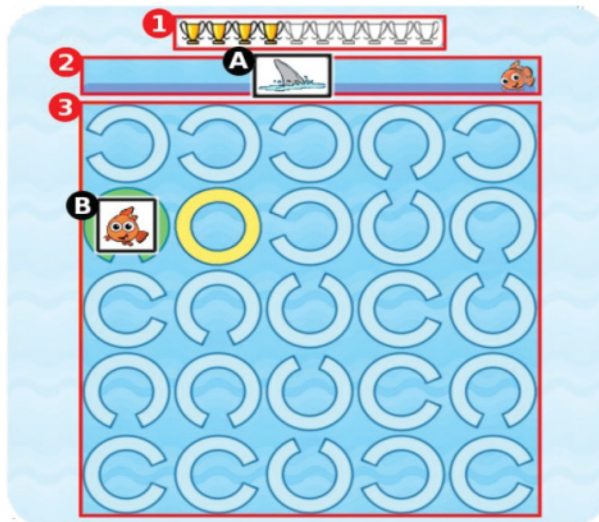

Fig. 8. Canvas and img instances used for the Paths game.

and `img` B represents the character of the game thus moving as the player makes her/his move.

5.3. Data Gathering

As previously discussed, the server collects data about performed exercises (i.e., game sessions) to measure the performance and progress of each user.

Information about users is collected on a MySql server. In order to address privacy issues, the system stores data about the performance of the players and their personal data (in XML) separately in two different databases. In this way, it is possible to extract data for statistical purposes without exposing personal data of the users, which remain accessible to authorized staff only.

The system collects information about each session of the game. As previously described, this information is initially stored on the client device, using the `localStorage` HTML5 feature to allow playing the game even off-line. Then, data are sent to the server and stored in the MySql database.

On the client side, data are collected as couples <key; value> and contain the user identifier, the level of the game and other information specific to each game (e.g., the letters used during that session, the duration of the session, the obtained score). All these data are stored in XML files at client side and then loaded into the MySql database when forwarded to the server.

In this article, we develop the first multifrequency MAC protocol for WSN applications in which each device adopts a single radio transceiver. The different MAC design requirements for WSNs and general wireless ad-hoc networks are compared, and a complete WSN multifrequency MAC design (MMSN) is put forth. During the MMSN design, we analyze and evaluate different choices for frequency assignments and also discuss the non-uniform back-off algorithms for the slotted media access design.

6. USER STUDY

We tested our serious games to verify their robustness, correctness and usability. More in detail, usability, that is, the effectiveness, efficiency, and satisfaction with which specified *users* achieve specified *goals* in particular *environments* [ISO 2008], has been tested through two phases, each of which involved a different set of users. The first set of users was composed of 10 children between 3 and 6 years old. We tested the system throughout the various phases of its development in order to evaluate the interaction usability both for children with some knowledge about standard input devices (e.g., mouse, keyboard) and for children lacking experience of computer interaction. The children also provided useful feedback about the difficulty level and other entertaining aspects of the games, which allowed us to develop games with the correct level of challenge and employing proper images and sounds to engage young players for several game sessions. Since the prescribed treatment could require children to play every day with our games for about half an hour, this result is particularly important to lower the therapy dropout rate.

Furthermore, the young age of the children requires specific care in avoiding images that could frighten them. For instance, the countdown timer during the Paths game sessions had initially been represented as a shark pin getting closer and closer to a child, with the pin (and the shark underneath) reaching the child at the timeout expiration. Unfortunately, younger children reported to be scared by this animation; but as soon as we changed the image of a child with the image of a red fish (see the time-bar on the top-most side of Figure 1), children did not complain anymore.

In summary, the first test phase allowed us to improve the design of the interface both from the usability and enjoyableness points of view. Even more important, it confirmed that even preschool children are able to use touch interface in a very natural way.

The second test phase lasted for 2 days and focused on the fully developed set of games. The group of test users employed in this context was chosen to represent the target audience; it hence included 24 children of the last year class in the kindergarten "Aquilone" in Padua, Italy. Before starting the tests, we used printed images of the system interface to briefly explain to each child the rules and goals of the various games. Then, each child had to play with all the games in our set, one after the other, in order to experience a complete session of the possible treatment.

We asked a feedback from our young testers and the outcome revealed that they considered the games enjoyable and sufficiently easy to play. For the sake of conciseness, in the charts presented in this article, we use the following acronyms to indicate the various games:

—P - Paths
—LVS - Local Visual Search
—HF - Hidden Fish
—FL - Fence Letter
—GVS - Global Visual Search
—W - Wizards

The first question that we asked to each child regarded whether she/he liked the game. Children could answer to the question with: "Yes, a lot", "Yes", "Not so much" or "No". The outcome of the collected answers is reported in Figure 9; on average, 77% of the children answered "Yes, a lot", only the Fence Letter game received some "No" answers, whereas for the other games "Not so much" was the worst answer received and it was provided only by very few of the children.

We also investigated the easiness experienced by the children in playing with our games. The outcome is depicted in Figure 10. On average, 67% of the children considered our games easy to play. A value higher than 50% but not too close to 100% is, indeed, desirable for the long-term attractiveness of a game, which is based on the right level of difficulty. If a game is perceived as too easy or too hard, a player would soon get tired of it [Schell 2008]. Our main goal was, indeed, to develop games that could be used as a daily training treatment. With too simple games, there would be no

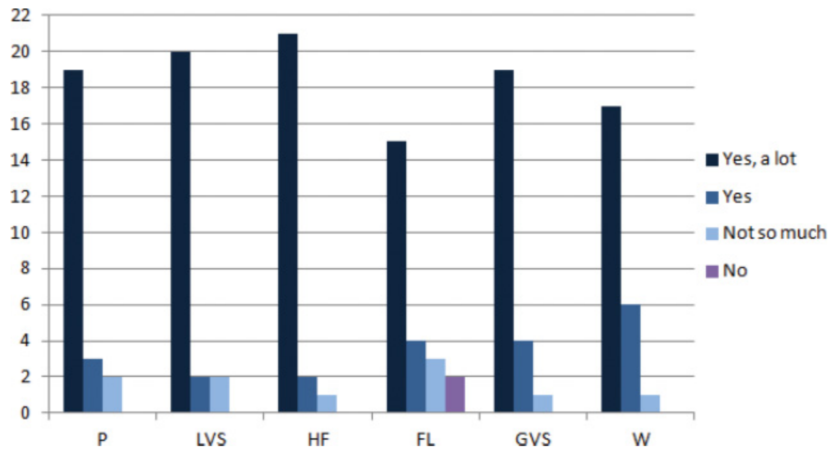

Fig. 9. Distribution of answers to the question: “Do you like the game?”.

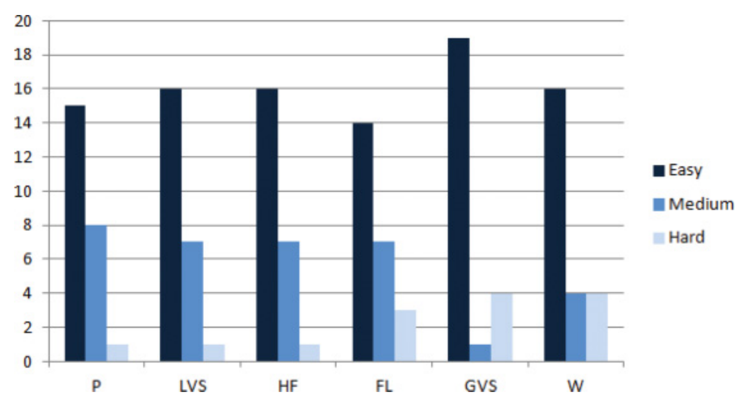

Fig. 10. Distribution of answers to the question: “Is the game difficult to play?”.

skill training; with too complex games, children would not have fun with them, thus refusing to play.

Other questions related to the single games aimed at pointing out bothering aspects of the game and perceived difficulty. Through these questions, we gathered information such as:

—difficulties due to the interaction modality;
—negative issues related to the graphical layout;
—problems in carrying out specific games.

The results underlined that the interaction modality was appropriate as the participants spontaneously and naturally interacted with the screen.

To increase the visual appeal of our games, we utilized images from a popular cartoon. The only problem we encountered was due to the image of a shark that was visualized each time the child did not solve the task correctly, both in the Paths game and in the Fence Letter game (leftmost in Figure 11). This image was considered to be too frightening: in one case, a participant decided to abandon the session. We hence substituted the shark image with a sad fish (rightmost in Figure 11).

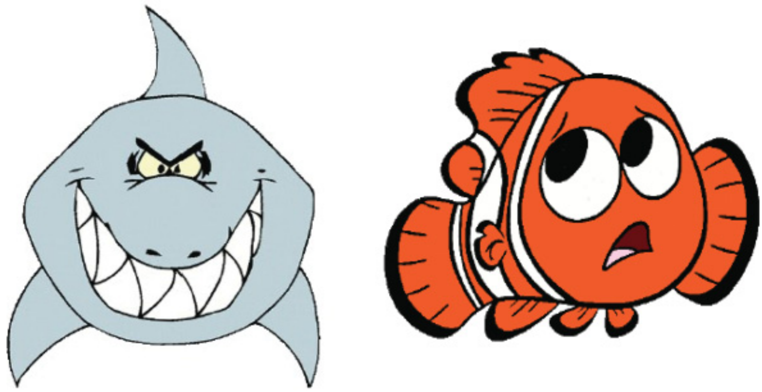

Fig. 11. Images displayed when the player loses: a threatening shark and a sad fish.

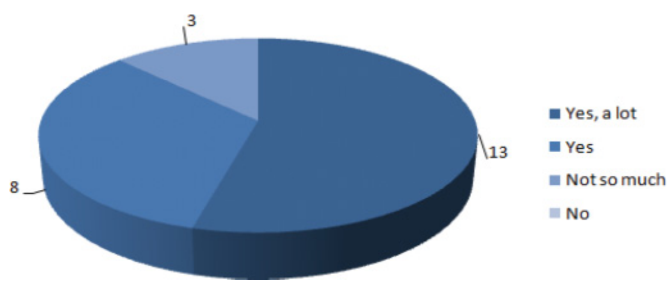

Fig. 12. Distribution of answers to the question: "Do you like to play with all these games?".

Issues in carrying out certain games (i.e., Paths, Fence Letter, Wizards) emerged to be due to misunderstanding of the rules or to the game structure itself. The questionnaire administered to the participants helped in discerning between these two causes:

(a) In the Paths game, the rules were found to be the main problem. We hence have modified the code so that, only in this phase of the test, it allowed the child to repeat the session to become acquainted with the game rules. We also increased the time available for the first session of each game.
(b) In the Fence Letter game, the main problem was the game structure itself. Indeed, the player is not allowed to make any mistakes as a single mistake leads immediately to the unsuccessful conclusion of the session: each time a shark goes through an opening, the session is over. The only possible solution, that is, decreasing the shark swimming speed, could make the game too easy and less motivating, thus losing effectiveness.
(c) The Wizards game was considered easy to understand but difficult to perform as the children were not able to discriminate the phoneme "A" from "E".

In conclusion, the games were enjoyable: 21 children out of 24 declared that they liked the game and 23 out of 24 wanted to repeat the experience (see Figure 12).

The only child who did not want to play the games again was the only non-native Italian speaker. This child had difficulties in understanding the instructions and, consequently, the experience was more frustrating than entertaining for her (as then reported in her questionnaire).

Last but not least, the questionnaire underlined the serious feature of the games. Even though a child reported to have been bothered by the sound of the letters in the

Table I. Energy Consumption

Game	Average Used Energy (mAh)	Expected Battery Life (h)
Paths	395.96	4.42
Local Visual Search	361.46	4.84
Hidden Fish	420.44	4.16
Fence Letter	395.81	4.42
Global Visual Search	350.73	4.99
Wizards	385.21	4.54
Means values:	384.94	4.56

Local Visual Search game, the participants lived the game experience as purely ludic (as intended).

6.1. Energy Consumption Test

Since the rehabilitation program has to be performed even using mobile devices, energy consumption is a crucial issue. Indeed, when deploying a smartphone or tablet application, the energy used by that application and the affect on battery life cannot be overlooked. Applications that waste a lot of energy, requiring frequent battery recharge, limit the freedom that mobile devices may provide, generating more stress to users than benefits.

For this reason, we made several tests in order to measure how much energy is needed by our games. Tests have been made with a Samsung Galaxy S II and the Power Monitor tester [Monsoon Solutions Inc. 2012]. This tester measures the power utilized by any device that uses a single lithium battery, providing information about power usage, current usage, expected battery life, etc.

Tests have been carried out playing with each game in sequence several times and registering data about *Average Used Energy* and *Expected Battery Life*, which are the two paramount metrics for our energy analysis. The Average Used Energy needs to be analyzed considering the (theoretical) capacity of the battery, which is 1,750mAh. Table I provides the outcomes of our tests.

As shown by the results provided in Table I, the power consumption depends on the particular game, but the child could play, on average, more than 4 hours before the smartphone or the tablet requires to be charged. This is particularly important for essentially two reasons. The first one is that if we consider that half an hour is enough for a child to perform her/his daily rehabilitation training (see Section 5), we can argue that the child is able to complete her/his daily rehabilitation without any charge. This gives her/him the possibility to play wherever she/he wants, increasing the engagement of children during rehabilitation. The second reason is that with this energy consumption a tablet could be used even in a doctor's office, since it could last even for half a day before needing to be charged.

7. RESULTS AND DISCUSSION

Although not specifically developed to be diagnostic tools, our games are based on neurocognitive functions that are impaired in children affected by DD (e.g., Gori et al. [2014]; for a recent review, see Gori and Facoetti [2015]). Therefore, we hypothesized that they could be also used as a support for individuating children at risk for DD.

About half of the reading deficits can be attributed to genetic influences [Gayan and Olson, 2001; Gori et al. 2015] and DD is known to frequently run in families [Fisher 1905; Hallgren 1950; Thomas 1905]. What is important for our study is that children with a dyslexic parent present a high risk to develop reading difficulties.

A total of 24 five-year-old children (12 females, 12 males, of which 23 were right-handed and 1 was left-handed) attending the last year of kindergarten were included

Table II. Scores and Response Times Recorded for the Paths Game

		NR	R
Score	Average	2.5	0.8
	Standard Dev.	1.4	0.7
Percentage of Won Games (%)	Average	68	32
	Standard Dev.	19	29
Response Time (ms)	Average	2116	2458
	Standard Dev.	256	408

in the present study. In the Italian school system, reading starts at the first grade; consequently, Italian preschoolers are also pre-readers. The performances of the youngest child were not considered since, during the tests, he was generally watching the games rather than playing with them, thus generating incomplete data.

Children were assigned to two groups based on their parents' score on the Adult Dyslexia Checklist [Vinegrad 1994]: 17 children were classified as pre-readers without familial risk for DD (No Risk group, NR), whereas the remaining 6 children were classified at risk for DD (At-Risk group, R). All children had no documented history of brain damage, or hearing or visual deficits. The IQ level of the children was estimated through the standard scores in similarities subtest of the WPPSI scale [Wechsler 2003]. The difference between the NR group and the R one was not statistically significant in chronological age (NR mean 63.6 months and R mean 64 months, $p > .05$) as well as in IQ level (similarities: NR mean 8.9 and R mean 10.5, $p > .05$).

We analyzed the children's performance with the serious games and compared the outcomes between the two groups (NR and R) to determine whether the game performances achieved by the children are different in the two groups so as to prove the effectiveness of our games in identifying the DD risk. In the following sections, we analyze the different games' outcomes.

7.1. Game #1: Paths

This task tested the participant's skills in focusing her/his attention on a specific point on the screen (the letter "C", graphically including the character), and to enlarge it on the next stimulus (another adjacent "C", into which the child has to move the avatar). Results show that the NR group obtained a higher score in comparison with R group, winning a higher number of matches and using less time. The average and the corresponding standard deviation for each group are reported in Table II.

We can conclude that this game can discriminate between the performances of the two groups, which achieved different (game) results in terms of both times and accuracy, excluding a possible tradeoff between speed and accuracy.

7.2. Game #2: Local Visual Search

In this game, children have to pick out a target (a little fish) among distracters. A shark appears on the screen when the child could not complete the task in a predetermined time or if she/he made too many mistakes; the shark was positioned closed to the target to also act as a cue.

Although in this task, the NR group has higher total scores and it exhibits shorter times of response than the R group (Table III), no significant difference between the two groups was found.

7.3. Game #3: Hidden Fish

This game required the children to match a different, specific sea creature, which appeared from behind some stones and remained visible for 2s. To complete the task, the

Table III. Scores and Response Times Recorded for the Local Visual Search Game

		NR	R
Score	Average	8.5	7.8
	Standard Dev.	0.95	1.47
Response Time (ms)	Average	2226	2424
	Standard Dev.	385	426

Table IV. Scores and Response Times Recorded for the Hidden Fish Game

		NR	R
Score	Average	7.5	7.2
	Standard Dev.	2.1	2.3
Accuracy	Average	0.67	0.60
	Standard Dev.	0.09	0.09
Valid Hint	Average	1842	2017
	Standard Dev.	151	57
Invalid Hint	Average	1968	1987
	Standard Dev.	197	394
Neutral Hint	Average	1924	2199
	Standard Dev.	162	238

Table V. Scores and Response Times Recorded for the Fence Letter Game

		NR	R
Score	Average	2.56	2.91
	Standard Dev.	1.54	2.55

child received some hints on the stones behind which the target was hidden; however, these hints could be correct, incorrect, or neutral.

This game aimed at evaluating the child's rapidity in orienting and focusing the visual attention toward a target. The results show that the response time differs in the two groups (see Table IV). The NR group exploited the hints, employing less time to touch the screen when provided with a valid hint and longer time in case of invalid hints, showing the typical spatial cuing effect [Posner 1980].

On the other hand, the R group was not able to use the valid cue to orient and focus visual attention, and detect the stimuli faster. The R group showed also particularly slow reaction times for the visual target in a neutral cue condition, suggesting a possible disorder in zoom-out their attentional focus or an attentional disengagement deficit. Regarding the other two kinds of hints, the R group showed no differences, demonstrating the difficulty of children at risk in exploiting the given clues.

7.4. Game #4: Fence Letters

In this task, the children had to close the openings in a stockyard shaped as a big capital letter, so that the sharks within could not escape. The aim was to help the child to implicitly learn the letter, even if focused on the local stimuli (the openings in the fence) and not on the shape of the letter. We could not find any significant difference between the two groups (see Table V) because of the following issues:

—some child lost the match at the very first mistake;
—sometimes the interface did not properly recognize the touches.

Consequently, we did not gain enough data to extract significant results.

Table VI. Scores and Response Times Recorded for the Global Visual Search Game

		NR	R
Score	Average	8.85	8.02
	Standard Dev.	1.21	1.93

Table VII. Played Matches Recorded for the Wizards Game

		NR	R
ISI 200 Score	Average	14.59	19.33
	Standard Dev.	4.52	6.53
ISI 80 Score	Average	14.24	9.33
	Standard Dev.	4.40	3.20
ISI 30 Score	Average	7.18	7.33
	Standard Dev.	3.23	4.08

7.5. Game #5: Global Visual Search

In this game, the children had to point out all the sea creatures composing a target shape displayed on the screen together with other randomly placed sea creatures). A delayed response time or a high number of mistakes would cause a shark to appear close to the next target. In this task, the two groups' performances did not differ. There seemed to be a trend of the R group in spending more time in moving to the successive interaction; yet, this was not statistically significant as shown by Table VI. A possible explanation could be that this game at basic level was too easy for both groups of children.

7.6. Game #6: Wizards

In this game, the children were required to discriminate between two brief speech-sounds, pointing out which one had been played first. The time gaps between the two speech-sounds were pre-fixed with 200ms, 80ms, and 30ms as Inter-Stimuli Interval (ISI) values.

Collected results described in Table VII emphasize that the children in the R group played a greater number of trails in the easier condition (i.e., ISI = 200ms) than children in the NR group who, instead, played a greater number of tests in the second condition (i.e., ISI = 80ms). The results for the last condition (i.e., ISI = 30ms) do not show significant differences between the two groups (a minimum number of trials at harder level was imposed by game structure). These findings show a difficulty due to the decrease of the ISI emerges and is different in the two groups: NR performed well with simplest level trials proceeding to the next level, whereas R stopped their performance at the simplest level.

7.7. Evaluation Summary

Even though the games were played by a limited set of children, they resulted in embodying a valid predictor of DD potential since the NR and R groups have shown different performances. The neurocognitive skills involved in DD were indeed engaged by the different games.

Considering these encouraging results and those reported by previous studies cited in the current literature focused on the possibility to modify game performances and the cognitive skills beneath them, the prolonged and intensive use of our games stimulating and training specific neurocognitive skills to successfully overcome the different game levels could positively impact on reading abilities [Green and Bavelier 2003; Franceschini et al. 2013].

8. CONCLUSION

DD is one of the more frequent neurodevelopmental disorders; it impairs the reading acquisition and is generally diagnosed during grade school, when reading difficulties can be registered. Yet, being able to detect and treat this frequent neurodevelopmental disorder even in preschool years would ensure better chances to limit its future impact on affected children.

To this aim, we have presented a system composed by various serious games designed for predicting the risk for DD even in preschool children. Once these children have been identified, our system can also be used to train rapid auditory skills and the visual-spatial attention, as well as letter-to-speech-sound integration, generally impaired in these children, in order to improve their future reading abilities.

The reported findings proved that our serious games can be played by preschool children as an entertaining and engaging activity, thus embodying a possible daily treatment with a low probability of dropout.

As mentioned in Section 1, this work is a (significant) step in a larger project. We are hence currently working to extend this research. First of all, we are already testing, with preliminary encouraging results, whether our serious games allow individuating children with a high risk of DD, based on the players' performance. However, we would like to refine our set of games by adding a fast action game, whose quick interaction requires an even more intense exploitation, and thus training, of reading related skills such as visual-spatial attention. We are also currently organizing an extensive set of tests in different kindergartens (already contacted and that responded enthusiastically) to validate the efficacy of our approach over a large population of pre-readers. Finally, we would like to check after 2 years whether our games correctly predicted the risk of DD and whether administrating them for 2 years represents an effective treatment.

ACKNOWLEDGMENTS

We are very grateful toward the anonymous reviewers who significantly helped us in improving the quality of this paper. Furthermore, we thank Simona Fantoni for her help in collecting data.

REFERENCES

Adobe Systems. 2012. Phone Gap Framework. Retrieved from http://phonegap.com/.

N. A. Beacham and J. L. Alty. 2006. An investigation into the effects that digital media can have on the learning outcomes of individuals who have dyslexia. *Elsevier Comput. Educ.* 47, 1, 74–93.

L. Beale, K. Field, D. Briggs, P. Picton, and H. Matthews. 2006. Mapping for wheelchair users: Route navigation in urban spaces. *Cartographic J.* 43, 1, 2006, 66–81.

M. Ciman, O. Gaggi, L. Nota, L. Pinello, N. Riparelli, and T. M. Sgaramella. 2013. HelpMe!: A serious game for rehabilitation of children affected by CVI. In *Proceedings of the International Conference on Web Systems and Technologies (WEBIST'13)*.

M. Csikszentmihalyi. 1990. *Flow: The Psychology of Optimal Experience*. New York, NY: Harper and Row.

A. De Bortoli and O. Gaggi. 2011. PlayWithEyes: A new way to test children eyes. In *Proceedings of the IEEE International Conference on Serious Games and Applications for Health (SeGAH'11).* 190–193.

D. Deponti, D. Maggiorini, and C. E. Palazzi. 2011. Smartphones physiatric serious game. In *Proceedings of the IEEE International Conference on Serious Games and Applications for Health (SeGAH'11).* 647–656.

I. Di Loreto and A. Gouaich. 2011. Mixed reality serious games: The therapist perspective. In *Proceedings of the IEEE International Conference on Serious Games and Applications for Health (SeGAH'11)*.1–10.

G. Esteban, C. Fernandez, V. Matellan, and J. Gonzalo. 2011. Computer surgery 3D simulations for a new teaching-learning model. In *Proceedings. of the IEEE International Conference on Serious Games and Applications for Health (SeGAH'11).* 1–4.

A. Facoetti, M. L. Lorusso, P. Paganoni, C. Umiltà, and G. G. Mascetti. 2003. The role of visuospatial attention in developmental dyslexia: Evidence from a rehabilitation study. *Brain Res. Cogn. Brain Res.* 15, 154–164.

A. Facoetti, N. Corradi, M. Ruffino, S. Gori, and M. Zorzi. 2010. Visual spatial attention and speech segmentation are both impaired in preschoolers at familiar risk for developmental dyslexia. *Dyslexia* 16, 226–239.

A. Facoetti, S. Franceschini, O. Gaggi, G. Galiazzo, S. Gori, C. E. Palazzi, and M. Ruffino. 2014. Multiplatform games for dyslexia identification in Ppreschoolers, In *Proceedings of the 11th IEEE Consumer Communications and Networking Conference (CCNC'14).*

G. Ferretti, S. Mazzotti, and D. Brizzolara. 2008. Visual scanning and reading ability in normal and dyslexic children. *Behav. Neurol.* 19, 87–92.

S. Ferretti, M. Furini, C. E. Palazzi, M. Roccetti, and P. Salomoni. 2010. WWW recycling for a better world. *Commun. ACM* 53, 4, 139–143.

J. H. Fisher. 1905. Case of congenital word blindness (Inability to learn to read). *Ophthalmol. Rev.* 24, 315–318.

C. Forlines, D. Wigdor, C. Shen, and R. Balakrishnan. 2007. Direct-touch vs. mouse input for tabletop displays. In *Proceedings of ACM CHI 2007 Conference on Human Factors in Computing Systems*. 647–656.

S. Franceschini, S. Gori, M. Ruffino, K. Pedrolli, and A. Facoetti. 2012. A causal link between visual spatial attention and reading acquisition. *Curr. Biol.* 22, 1–6.

S. Franceschini, S. Gori, M. Ruffino, S. Viola, M. Molteni, and A. Facoetti. 2013. Action video games make dyslexic children read better. *Curr. Biol.* 23, 1–5.

M. Furini. 2007. Mobile games: What to expect in the near future. In *Proceedings of the GAMEON Conference on Simulation and AI in Computer Games* (Bologna, Italy).

J. D. Gabrieli. 2009. Dyslexia: a new synergy between education and cognitive neuroscience. *Science* 325, 280–283.

O. Gaggi and M. Ciman. 2015. The use of games to help children eyes testing. *Multimedia Tools and Applications*, 2015.

O. Gaggi, G. Galiazzo, C. E. Palazzi, A. Facoetti, and S. Franceschini. 2012. A serious game for predicting the risk of developmental dyslexia in pre-readers children. In *Proceedings of the 21th IEEE International Conference on Computer Communications and Networks (ICCCN'12)*.

M. A. García-Pérez. 1998. Forced-choice staircases with fixed step sizes: Asymptotic and small-sample properties. *Vis. Res.* 38, 12, 1861–1881.

J. Gayan and R. K. Olson. 2001. Genetic and environmental influences on orthographic and phonological skills in children with reading disabilities. *Develop. Neuropsych.* 20, 2, 487–511.

M. Gerla, D. Maggiorini, C. E. Palazzi, and A. Bujari. 2013. A survey on interactive games over mobile networks. *Wiley Wirel. Commun. Mobile Comput.* 13, 3, 212–229.

C. Green and D. Bavelier. 2003. Action video game modifies visual attention. *Nature* 423, 534–537.

S. Gori and A. Facoetti. 2015. How the visual aspects can be crucial in reading acquisition: The intriguing case of crowding and developmental dyslexia. *J Vis.* 15, 15.1.8.

S. Gori, P. Cecchini, A. Bigoni, M. Molteni, and A. Facoetti. 2014. Magnocellular-dorsal pathway and sublexical route in developmental dyslexia. *Front Hum Neurosci.* 8:460.

S. Gori, S. Mascheretti, E. Giora, L. Ronconi, M. Ruffino, E. Quadrelli, A. Facoetti, and C. Marino. 2015. The DCDC2 intron 2 deletion impairs illusory motion perception unveiling the selective role of magnocellular-dorsal stream in reading (dis)ability. *Cereb Cortex.* 25, 1685–1695.

B. Hallgren. 1950. Specific dyslexia (congenital word-blindness): A clinical and genetic study. *Acta Psychiatrica et Neurologica, Supplement* 65, 1–287.

ISO 9241-171. 2008. Ergonomics of human-system interaction – Part 171: Guidance on software accessibility.

P. Jaśkowski and P. Rusiak. 2008. Temporal order judgment in dyslexia. *Psychol Res.* 72, 1, 65–73.

P. M. Kato. 2010. Video games in health care: Closing the gap. *Rev. General Psych.* 14, 2, 113–121.

A. Kevan and K. Pammer. 2008. Visual deficits in pre-readers at familial risk for dyslexia. *Vis. Res.* 48, 2835–2839.

R. Koster. 2013. *Theory of Fun for Game Design.* Second Ed. O'Reilly Media.

H. Lyytinen, M. Ronimus, A. Alanko, A. Poikkeus, and M. Taanila. 2007. Early identification of dyslexia and the use of computer game-based practice to support reading acquisition. *Nordic Psych.* 59, 2, 109–126.

M. Ma and K. Bechkoum. 2008. Serious games for movement therapy after stroke In *Proceedings of IEEE Conference on Systems, Man and Cybernetics*.

A. Magnan and J. Ecalle. 2006. Audio-visual training in children with reading disabilities. *Elsevier Computers & Education* 46, 4, 407–425.

D. R. Michael and S. L. Chen. 2005. Serious games: Games that educate, train, and inform. *Muska and Lipman/Premier-Trade*.

C. E. Palazzi, M. Roccetti, and G. Marfia. 2010. Realizing the unexploited potential of games on serious challenges. *ACM Comput. Entertain.* 8, 4, 4–7.

F. Pittarello and R. Stecca. 2010. Querying and navigating a database of images with the magical objects of the wizard Zurlino. In *Proceedings of the 9th International Conference on Interaction Design and Children*, 250–253.

M. Plaza and H. Cohen. 2007. The contribution of phonological awareness and visual attention in early reading and spelling. *Dyslexia* 13, 67–76.

M. I. Posner. 1980. Orienting of attention. *Quarterly Journal of Experimental Psychology* 32, 3–25.

Power Monitor, Monsoon Solutions Inc. Retrieved fhttp://www.msoon.com/LabEquipment/PowerMonitor/.

Practice. 2012. McGraw-Hill Education: Government in Action. Retrieved from at http://www.mhpractice.com/.

L. A. Ripamonti and D. Maggiorini. 2011. Learning in virtual worlds: A new path for supporting cognitive impaired children. In *Proceedings of the 14th International Conference on Human-Computer Interaction (HCI 2011)* (Orlando, FL), 462–471.

M. Roccetti, G. Marfia, and C. E. Palazzi. 2011. Entertainment beyond divertissement: Using computer games for city roads accessibility. *ACM Comput. Entertain.* 9, 2.

M. Roccetti, G. Marfia, and A. Semeraro. 2012. Playing into the wild: A gesture-based interface for gaming in public spaces. *J. Vis. Commun. Image Represent.*, 23, 3, 426–440.

L. Ronconi, D. Basso, S. Gori, and A. Facoetti. 2014. TMS on right frontal eye fields induces an inflexible focus of attention. *Cereb. Cortex* 24, 396–402.

L. Ronconi, L. Franchin, E. Valenza, S. Gori, and A. Facoetti. 2015. The attentional 'zoom-lens' in 8-month-old infants. *Dev. Sci.* 2015 Feb 20. DOI:10.1111/desc.12288

Y. Sasaki, J. E. Nanez, and T. Watanabe. 2010. Advances in visual perceptual learning and plasticity. *Nat. Rev. Neurosci.* 11, 53–60.

J. Schell. 2008. *The Art of Game Design.* Elsevier, Inc.

A. R. Seitz, A. Protopapas, Y. Tsushima, E. L. Vlahou, S. Gori, S. Grossberg, and T. Watanabe. 2010. Unattended exposure to components of speech sounds yields same benefits as explicit auditory training. *Cognition* 115, 435–443.

A. R. Seitz and T. Watanabe. 2003. Is subliminal learning really passive?, *Nature* 422, 36.

E. G. Steenbeek-Planting, M. Bott, M. van der Ven, N. M. Swart, and D. van der Hout. 2013. Evidence-based psycholinguistic principles to remediate reading problems applied in the playful app Letterprins: A perspective of quality of healthcare on learning to read. *Games for Health.* 281–291.

P. Tallal. 2004. Improving language and literacy is a matter of time. *Nat. Rev. Neurosci.* 5, 721–728.

C. J. Thomas. 1905. Congenital word blindness and its treatment. *Ophthalmoscope* 3, 380.

L. van den Audenaeren, V. Celis, V. van den Abeele, L. Geurts, J. Husson, P. Ghesquière, J. Wouters, L. Loyez, and A. Goeleven. 2013. DYSL-X: Design of a tablet game for early risk detection of dyslexia in preschoolers. *Games for Health* 257–266.

M. Vinegrad. 1994. A revised adult dyslexia checklist. *Educare* No. 48.

D. Wechsler. 2003. *Wechsler Preschool and Primary Scale of Intelligence Revised.* The Psychological Corporation.

M. Zorzi, C. Barbiero, A. Facoetti, I. Lonciari, M. Carrozzi, M. Montico, L. Bravar, F. George, C. Pech-Georgel, and J. C. Ziegler. 2012. Extra-large letter spacing improves reading in dyslexia. *Proceedings of the National Academy of Science USA* 109, 11455–11459.

M. Zapusek, S. Cerar, and J. Rugelj. 2011. Serious computer games as instructional technology. In *Proceedings of the 34th International Convention MIPRO*. 1056–1058.

Received October 2013; revised February 2014; accepted March 2014