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The use of games to help children eyes testing

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Abstract A doctor cannot perform a good diagnosis without the user collaboration. One of the major problem for ophthalmologists with children is to capture and maintain their attention while performing their tests. Sometimes children give wrong answers, or not accurate, since they are no longer interested in the task. In this paper we use the *serious game* paradigm to help children eyes testing. We ask the children to perform a vision acuity and a daltonism test using our game *PlayWithEyes*. Children have to recognize symbols projected on a wall and point them in a touch interface which displays all the possible answers. Tests performed in a kindergarten with 65 children have shown that the use of our game helps to obtain children cooperation because they have fun, so their attention may last longer, thus improving the possibility to perform a correct diagnosis especially for very young children. This is particular important for some sight defects like amblyopia (lazy eye). Moreover, the system allows us to identify visual acuity reduction in two children. Tests also highlight some limitations of the tool which have been promptly fixed.

Keywords serious games · game-based diagnosis · assistive technologies · multimedia applications · mobile devices · natural human interaction;

1 Introduction

Patient's collaboration is very important for doctors to perform a good diagnosis, but it cannot always be taken for granted, especially when dealing with children. One of the major problems, in this case, is to capture and maintain

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their attention. This is particularly true for ophthalmologists that have to test children eyes, asking them to look at some projected letters and to recognize their orientation. This task is so boring for children that sometimes, especially for very young children, their responses become not accurate, or even wrong, since they are no longer interested in the task. Unfortunately, there exist some eye diseases for which an early diagnosis is very important: *amblyopia*[1], commonly known as *lazy eye*, is one of them [16].

Treatment for amblyopia begins as soon as possible after diagnosis and an early treatment (before age 6) usually can reverse the condition. Some studies ([33], [13]) have shown that earlier diagnosis allows better results.

The same problems arises with color blindness (daltonism). Color blindness is defined as the inability or small ability to see colors or perceive color differences that may cause the impossibility for the person to distinguish two different colors (like orange and green) [34]. A color vision problem can have a big impact on person's life. In children, color vision problems can affect learning abilities and reading development, and may limit career choices.

For all these reasons, a tool which helps to obtain children attention and collaboration can be very important to perform an early diagnosis and to allow a correct treatment. In this paper we present *PlayWithEyes*, an application which aims at testing children eyes through the use of a game. We implement different exercises to explore visual ability: vision acuity test, daltonism test, and crowding test. These tests are performed using Lea symbols [28], alphabetical letters and images that are projected on a wall.

Different from already existing system, the children interact with the system using a touch interface, i.e., an Apple® iPod Touch, which displays several possible answers to the test. During all the development we pay much attention in minimizing system requirements and encumbrance to increase portability: it only requires a tablet, a smartphone and a monitor.

In order to obtain children collaboration, we use the *serious game paradigm*, so that children can have fun playing a game without understanding that they are testing their eyes. Children are engaged and encouraged with audio messages, e.g., an applause in case of correct answer. Images taken from popular cartoons are projected together with test symbols/letters/images.

A simple test for each child is based on several exercises, where "questions" are projected on the wall and possible answers are presented on an iPod Touch. For the acuity test, the child has to choose the right letter or symbol showed on the wall. The system provides different acuity tests, using letters, Lea symbols or the "E" chart, also called tumbling "E", i.e., different rotation of the letter "E". Daltonism tests require children to choose the image that represents the right Ishihara path that they are able to see.

We aim at providing a very friendly interaction, even for younger patients. For this reason, we create two interaction modalities, a very simple one for

[1] Amblyopia is the eye condition denoted by reduced vision not correctable by glasses or contact lenses, since is not due to any eye disease. The brain, for some reason, does not fully acknowledge the images seen by the amblyopic eye. 3% of children under six and 1-5% of population have some form of amblyopia.

younger children, and an interaction more similar to games to involve older children. The use of the *serious game paradigm* helps to improve the diagnosis of very young children, because the eye test is able to capture the users attention since they have fun, allowing the doctor to better observe the little patient.

PlayWithEyes has been tested with 65 children from a kindergarten, with ages ranging between 3 and 5 years old. The evaluation of our tests showed that we reach positive results both for the *serious* part of the system, i.e. test and evaluate visual acuity and daltonism in children with an efficient use of the time, and from the *game* part of the system, i.e. children were engaged by our games and positively accept the exercises. The combination of this two evaluations shows that our system can be a valid substitute to the normal tests used by ophthalmologists to measure visual acuity in children.

Preliminary ideas about the development of this system appear in [17], but this paper does not contain any discussion about system evaluation and testing, which are described here. Moreover, it contains a very preliminary version of the system which, for example, proposed different exercise, that do not use the entire alphabet and that following tests showed to be inefficient for daltonism.

The paper is organized as follows: Sections 2 and 3 describes background and the state of the art of *serious games* and studies on interaction and engagement of children. In Section 4 we present the overall system and the designed interaction modes. Section 5 describes the requisites of the system and the architectural choices made to develop a *portable* system. Section 6 describes how we deal with the problem of adapting the size of the test images depending on the resolution of the screen and the distance at which the test is made. Tests made with our system and the obtained results are discussed in Section 7. We finally conclude in Section 8.

2 Background on Serious games

In the last few years the interest around *serious games* is growing extremely fast, due to the possibility to use them in several areas, even with completely different objectives and principles, increasing people engagement in particular tasks and training.

Serious games can be defined as a virtual interactive simulation that is presented as a game, with the purpose to hide, under this game, more serious purposes.

The main objective of the *serious games* is to make people have fun, and to teach them, in a funny way, particular skills and capabilities, that can be applied in the real world. *Serious games* can be much more engaging than the other typical teaching strategies. If the user has fun, he/she will probably continue to play, learning in a faster way what the game wants to teach to him/her, and at a certain point, he/she begins to apply that particular behavior in the real world without the game.

Serious games are actually used in several areas. The first historical area for employs is the military one, where *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 usually populate the real world, in order to make them able to take decisions faster and safer. Other application areas are the governmental field (with application to simulate population's reaction to politicians decisions [29]), educational field (with application for children to increase their memorization abilities or for a different teaching strategy [35]) or to train particular behavior for employs.

One important application field, that we want to focus on, is the medical field, where *serious games* can be used either for doctors and for patient treatments. When we talk about *serious games* for doctors, we refer to all the simulations and virtual environments that are used to teach particular procedure to new doctors, in order to increase theirs abilities before they operate on real people [32].

Another possible usage of *serious games* is to deal with patients. The main situations where they can be used are:

- health monitoring for emotional states tracking [10];
- rehabilitation after strokes [11];
- elderly support in everyday life [23];
- educate people to more healthy behaviors [9] and
- stimuli to practice constant physical activity [27].
- diagnosis and rehabilitation of children affected by particular disabilities [14]

It is easy to see that *serious games* can be used either for older patients and for the youngest ones. In particular, for the latter, they can be extremely useful because they are able to get the attention of children, and so they can be used to engage them and perform, for example, an assessment of a particular disease or to perform a rehabilitation program that could last a long period of time, even at home and not only at hospital.

3 Related Works

Since our system is specifically intended for preschool children, we must pay particular attention to the interface and how to engage children in this particular way of testing their visual acuity. Many papers address the problem of interfaces for children. One possibility is to use what are called *tangible interfaces*, that use physical artifacts for accessing and manipulating information, as shown in [30]. In this paper, preschool children navigate and access images stored in a database through physical and magic objects of wizard Zurlino.

On the other side, Forlines et al. [19] investigate the differences between mouse and direct touch input, both in terms of quantitative performance and subjective preference. They conclude 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, that are even called "Digital Native Speaker", where touch interaction seems to be much more natural for them, therefore not much training is necessary to teach them how to interact with touch applications.

Other papers in literature presents the design *serious games* to deal with children affected by particular diseases. Kato explores the positive aspects of using existing commercial video games for health improvements or surgical training, and tailor-made game for particular disease group in order to improve recovery and rehabilitation of patients [24]. She defines Re-Mission, a game to help young patients to understand and deal with cancer: game characters represent the drug which destroys cells with cancer. Moreover the game also provide patients a forum to discuss together.

DYSL-X [8] integrates Dyslexia predictors in a tablet game, to capture children attention to obtain a more accurate measurement. The authors evaluate several existing games for preschoolers to derive a set of guidelines to design a optimal tablet game for the 5 years children, then these guidelines are used to develop Diesel-X, a game about a robot dog, Diesel, which has to fight against a gang of criminal cats.

HelpMe! [14] is a serious game to help the rehabilitation process for children affected by CVI (Cerebral Visual Impairment). The game is able to adapt the rehabilitative exercises to each particular child, and can follow the improvements of the patient, to reduce the influence of this disability in future life. Moreover the system can help doctors to perform a good assessment of a patient and to create a rehabilitation program.

Gaggi et al. [20] developed a set of *serious games* to identify Developmental Dyslexia in order to detect this disability at early stages and immediately start a therapy. These *serious games*, with the characters from the *Nemo* cartoon, were designed to be accessible from any devices, both tablet using a touch interaction or a PC using a keyboard and a mouse, to give the possibility to the doctor to choose the best interaction method depending on the age and the ability of the child.

3.1 Existing Software

A certain number of software products that provide vision tests exist, both for professional and personal use. At the state of the art the main professional solutions that can be adopted by ophthalmologists are listen below:

- 20/20 Vision (Canela Software) [12]
- PVVAT^{TM} (Precision Vision) [31]

Both products are desktop applications for professional use. The software shows the tools used by ophthalmologists (eye charts, Snellen tables, etc.) on the desired screen to test patients. The screen can be either a computer monitor or an external display. Both products do not focus on testing children patients specifically, even though Lea optotypes can be used. Moreover, these solutions do not use a game paradigm to improve users' attention.

Given the proliferation of mobile phones, another set of interesting software solutions are applications that allow users to self test their visual acuity with a cell phone or a portable device. The relevant applications are:

- Acuity (Intellicore) [22]
- EyeChart HD (Dok LLC) [18]
- Vision Test (3 sides cube) [1]
- FastAcuity Lite (KyberVision Consulting, RD) [26]
- Vision (AppZap) [4]
- iC Pro: The EyeTest (Konrad Feiler) [25]

All the listed applications for iPhone, iPod Touch or iPad, behave almost in the same way with non perceptible differences. They propose daltonism tests based on Snellen tables and acuity tests based on eye charts and Landolt rings. Applications like these, often developed with no strong specifications, provide nothing more than simple self-made tests with no real implications.

Comparing our solution with this state-of-the-art applications, it is clear that our improvements are both in the *serious* and in the *game* part of the system. For the *serious* part, as we will see in Section 7.1, with our system it is possible to correctly evaluate visual acuity of children as normal tests used by doctors. On the *game* part, differently from other applications, we consider and tackle the problem of children engagement, showing how our system is able to engage children and so to perform eye tests without annoying them, with the risk of having wrong answer due to a reduction in their concentration. Moreover, our system can work in any situation, in terms of distance from the projected optotypes, size of the screen, availability of a wireless connection and age of the children.

4 Description of the game "PlayWithEyes"

PlayWithEyes is a serious game which can be used both in kindergartens and doctor's surgeries with different implications. In the first case, the game uses a set of pre-configured tests, studied by a group of ophthalmologists, so the teacher can easily test children during a normal school day, simply inserting their names. Children can be inserted in the database and classroom can be created before the test, in order to lower the waiting time between a child and the next one. This is particularly important because we do not want the children get impatient while waiting, since bored patients can provide casual answers, during tests, only because they are tired. Each child is tested individually and the report, obtained while playing, indicates if the child needs a specific visual examination by an ophthalmologist. In this way, our system helps a quick and widespread screening of children.

If used by a doctor, our system is just a facility for the ophthalmologist to obtain a better cooperation from the children, because as long as they have fun, they continue playing, thus testing their visual acuity. This helps to obtain a more precise sight assessment, since the eye test may last longer, and the child maintains the attention, thus improving the possibility to perform a correct diagnosis for very young children.

Finally, the system has to store and retrieve data acquired during tests. In particular, for each tested child the system has to store the proposed test and the answer of the child, eventually reporting children with evidences of visual problems.

4.1 Visual acuity tests

Visual acuity tests were initially designed using the standard Lea symbols [28]. Lea symbols, shown in Figure 1, are specifically defined for preschool children because of their simplicity: children are able to refer to them without ambiguity even if they cannot read letters. The original[2] symbols are four: a house, an apple, a square and a circle.

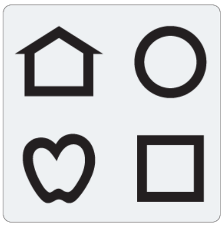


Fig. 1: Lea symbols used to test visual acuity for children

Another possibility is the use of the tumbling “E”. The child has to select the correct orientation of the projected letter.

The most common optotypes used for letters are the Snellen optotypes (Figure 2) but, they do not include all the different letters. Moreover, we need to resize the optotypes for acuity tests, so we need to draw our optotypes for the remaining letters. Each letter is drawn in a 10x10, resizable, grid, where each cell can be colored in black or white. To write letters which need curves, e.g., letters “B” and “C”, some cell can be half colored. The final list of optotypes is shown in Figure 3.

Fig. 2: Snellen optotypes with alphabetical letters

[2] Some minor variants with additional optotypes are also used in ophthalmology.

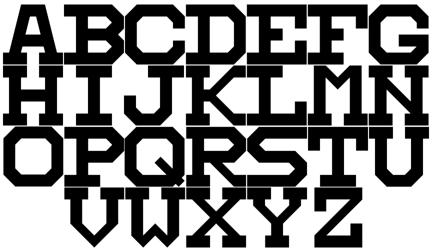


Fig. 3: Our letters optotypes

Symbols and letters can be displayed one at a time, or inside a row or a matrix. The first test is simpler for the children, the other two, also called “crowding test”, increase the difficulty for the children, who have to recognize a symbol inside crowded interface. In this case, the symbol to recognize is indicated by an arrow, when symbols are displayed on a row, or by a surrounding square, when symbols are displayed in a matrix.

4.2 Test of color blindness

As mentioned before, *PlayWithEyes* has been developed even to test Daltonism. The first version of the Daltonism tests asked the child to recognize the right color of a chameleon that is projected, choosing between four different possibilities.

During tests, several problems arises. Despite the initial decision to use only 6 different colors proposed by Lea, the difficulties related to the representation of these colors in an external monitor (like brightness, contrast and gamma correction of the monitor or the brightness of the environment) negatively affected the effectiveness of the tests, since it is not possible to guarantee that a given color is represented in exactly in the same way in any monitor (a description of this evidence is provided in Section 7.1). For these reasons, we decided to introduce a new kind of test. Despite of recognizing the color showed on an external monitor, the child has simply to recognize a path that is unrecognizable for children affected by daltonism. We use the Ishihara plates shown in Figure 4, that represent a path inside a circle, using specific colors not distinguishable for persons with daltonism[3]. Images projected on a wall or showed on a screen to the child are colored, but the interface for the child shows the black and white version of the images, where the background is black while the internal path is white. Figure 5 shows the black and white conversion of the Ishihara plates.

[3] We note here that paths represented in Figure 4 cannot be identified when the figure is printed in black and white since Ishihara plates aims to evaluate color blindness.

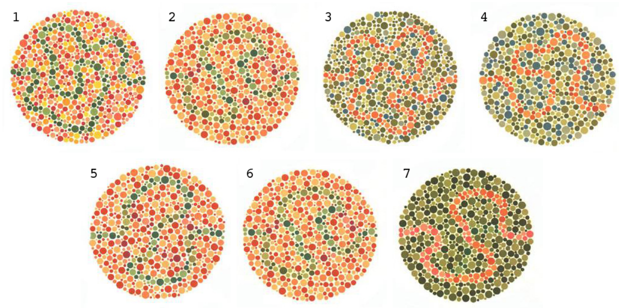


Fig. 4: Ishihara plates

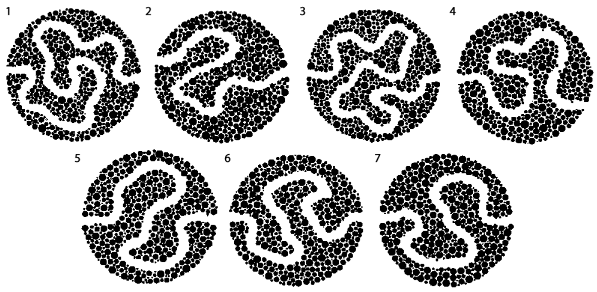


Fig. 5: Black and white version of the Ishihara plates

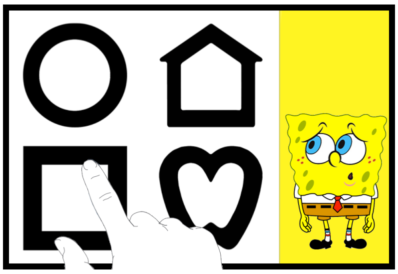
4.3 Interaction methods

The system lets the possibility to the child to interact with the game in two different ways, depending on his/her capabilities to deal with touch interfaces: touch or drag interaction.

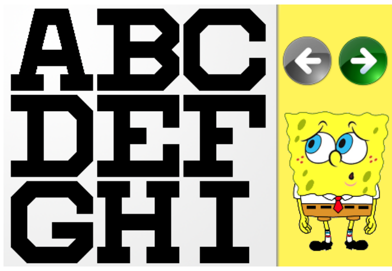
Lets consider the touch interaction. This is the easiest way for the child to provide an answer, since it requires the lowest level of interaction (and complexity) for the child. He/she has simply to touch the image that represents his/her answer as depicted in Figure 6.

To increase the engagement of child, which is extremely important if we want to maximize the concentration of the child and the correctness of his/her answers, several solutions have been adopted. First of all, the test and its possible answers (symbols or letters) are decorated with some cartoon characters on the background, in a number that does not create negative interference with the examination during the game play. Secondly, some non-misleading animations and sound are used every time he/she provides the answer to the test, e.g., an applause in case of correct answer, to enhance the game experience.

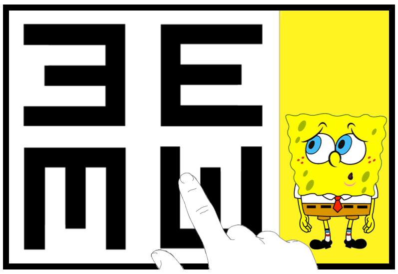
The second interaction mode uses the dragging or panning operations, moving an image on the surface of the touch screen: in Figures 7(a) and (b) the user has to move the cartoon character (in particular, an image of the



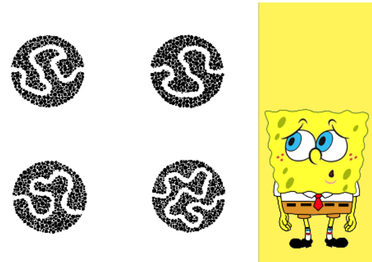
(a) Crowding test with LeaSymbols



(b) Crowding test with letters

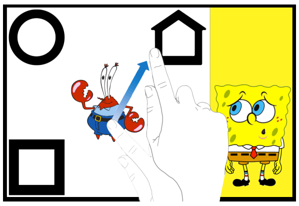


(c) Rotation test

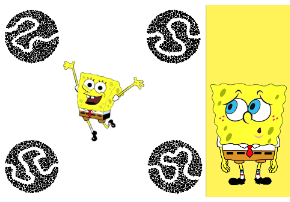


(d) Daltonism test

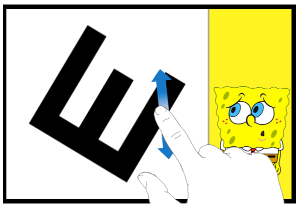
Fig. 6: Child interface with touch interaction



(a) Crowding test with LeaSymbols



(b) Daltonism test



(c) Rotation test

Fig. 7: Child interface with drag interaction

SpongeBob SquarePants® world) over the right answer. This kind of interaction is more difficult than the first one, and is more suitable for older children.

In case of the rotation test, which uses “E” chart, the child has to rotate the letter until the position on the screen corresponds to the projected one, and submit the answer clicking on another *SpongeBob*® image (see Figure 7(c)).

The touch interaction is the only one available when dealing with all the letters since the total number of choices for the question is too high to be able to show all of them with the iPod/iPhone screen in a way that it is possible to move a cartoon character over one of them, since the images of the letters become too small. So, the set of possible answer is divided into two different subsets, and the child uses two arrows and the touch interaction to move between the two subsets as depicted in Figure 6 (b).

5 System Requirements and Architecture

Users of the system may have essentially three different roles:

1. **Administrator:** can configure the set of games proposed to the children. Moreover, it send data about patients and their game performances to the doctor. The teacher or the doctor may have this role;
2. **Player:** children who play with the *serious game*;
3. **Consultant:** data collected during the game play can be stored into a Microsoft Excel file and sent by email to a consultant. Otherwise he/she has the possibility to read this data and evaluate performances of each child using the system through the doctor’s interface.

PlayWithEyes has a classic server-client behavior, based on the following components:

- **Server:** used by the administrator to configure the vision tests. It is responsible to create, manage and show the exercises, but also to provide data to consultant for further analysis;
- **Client:** used by the children to play the game, it is responsible to show the possible answer and to collect the users choices.

In addition to these components, an external display is necessary to show the acuity or daltonism tests. In this case, we can use either an external monitor or a projector that shows the images on a wall. Figure 8 shows the architecture of the system. As we can see, the architecture follows a common client-server architecture. The server is responsible to manage the communication with the client that is used by the child to submit the answers. Moreover, it is connected to the projector or the external display and manages the images to show. Finally, it must save, in a privacy preserving mode, all the data acquired during tests, and to forward this data only to consultants for a following analysis.

The system has been designed to perform the game in 5-10 minutes per child, a time sufficient to test visual acuity and the ability to distinguish colors. Every game session is organized as follows:

1. the test symbols are projected on the display, with background images that show cartoons characters, in order to engage the child during all the time

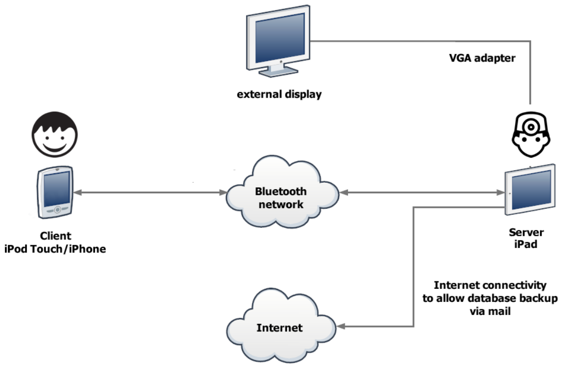


Fig. 8: The architecture of the system, with a client-server behavior.

of the test; no music or audio comments are played in this phase to allow the child to focus on the answer;

2. the child chooses the answer on his/her device, depending on what he/she is able to see;
3. the server receives data and stores them in a persistent way. Doctor can analyze them in a second moment.

As already discussed in Section 4, our system can be used in two different environments, kindergarten and doctor's surgeries. In both environments, two different problems must be considered. The first one is related to space. Since the available space is not usually extremely high, the system should minimize the required space and encumbrance. This means that, for example, wireless connectivity should be preferred to the wired one, and even the usage of a PC should be replaced with something smaller and more portable.

The second problem is related to the infrastructure. In particular, it is not possible to rely on the hypothesis that a (wireless) Internet connectivity will be available during tests. This is particularly true when tests are performed in a kindergarten, since not all buildings are equipped with this infrastructure. This means that, the need to connect to an Internet application or to rely on online service reduces the portability of the system. Therefore, a Bluetooth® connectivity is used between client and server instead of WiFi connection.

As already mentioned, the actors that interact with the system are kindergarten teachers, oculists and children. None of them are supposed to have any special knowledge about the usage of computers, therefore during all development phase, we consider as an important target to achieve the creation of a simple and easy-to-use product with a friendly interface for final users. Devices which require minimal configurations and provide touch interfaces are preferred among traditional computers, since, according to discussion in Section 3, touch interfaces are best suited for children, that are naturally inclined to interact with the outside world through touch.

Mobile solutions also allow us to reduce the total amount of space required for the entire system, so the possible choices are the Apple® iPad/iPod or the Android devices. We investigate also the possibility to develop a cross-platform application, and let the users choose the best hardware setup depending on preferences, budget etc. With this kind of approach, it is possible to develop only one single application that is further converted into two different native applications that can be used on the target devices, one in Objective-C for Apple devices or Java for Android ones. For this solution, several frameworks are available. PhoneGap [2] gives the possibility to develop an HTML, CSS and Javascript application, while Titanium [3] has its own language and APIs, based on Javascript, that are used to build the application that will further into native applications. The tests made with both of these frameworks have shown that they are not mature for our purposes because Bluetooth connectivity and the possibility to connect the device to an external monitor to show different content from what is shown on the tablet device are not fully supported by the frameworks and for both the platforms.

Giving the fact that a cross-platform development is not possible, we decided to develop an iOS application instead of an Android one for two reasons. The first one is that the Android world has a high variety of devices, of different screen dimensions, operating system etc., and so it would not be possible to guarantee the compatibility of the system with all the devices. The other reason is that the Android devices has a more complex design, in particular they have much more physical buttons that could become misleading for children, attracting them to touch all the buttons, and suspending the game in some cases, instead of focus on the game.

Therefore, we use an Apple® iPad for the device (we call the server application *iPadSight*) used by the teacher and one iPod Touch or an iPhone for the child (we call the client application *iPodSight*). Moreover, an external visual display unit is also needed to execute the vision screening tests.

PlayWithEyes has being developed on iOS operating system, the Objective-C language and the Cocoa framework [5]. The communication is supplied by the *GameKit* framework [6], whose main focus is to wrap the well-known *Bonjour* implementation of the *Zeroconf* protocol in order to establish a communication channel between two devices without asking users any configuration parameters. The *UIScreen* class provided by Cocoa in the *UIKit* framework [7] enables the possibility to handle an external screen and to decide what to display on it.

Given the described architecture, we defined the following requirements:

1. *iPadSight* must manage users and tests;
2. *iPadSight* and *iPodSight* must adopt the Bluetooth® wireless protocol to communicate with each other;
3. *iPadSight* must connect to an external screen and manage what to display on;
4. *iPodSight* is the interface of the serious games for kids that must be easy-to-use and funny.

The first requirement allows to create, delete and edit users, classroom and tests, but it is also necessary to keep track of the screening results in order to transmit data to oculist for diagnosis, in the case of screening in a kindergarten, and to allow statistic analysis. The Bluetooth® protocol (requirement #2) allows the system to work even in absence of a wireless network: once more, we minimize the system requirements in term of hardware components[4]. Moreover, the development of the system has shown that Apple devices allow Bluetooth® communications in a very simple way.

During eye tests, children have to respond interacting with the *iPodSight*, in accordance to what they are able to see displayed on the screen at a given distance. At the same time, the doctor uses the *iPadSight* to watch what the system is showing to the child and to control the test progress. In this way, the doctor/teacher can control the answers already given by the child (correct/wrong) and get an idea of the remaining exercises necessary to complete the test. Figure 9 shows the user interface for the doctor/teacher. The system reports the child responses on the bottom section of the interface: for each sizes of the optotypes, the green check marks indicate a correct answer, the red "X" depicts a wrong answer, and the yellow dash means that the child does not give an answer. If more exercises use the same optotypes' size, an "X" is displayed if the child gives at least one incorrect answer.

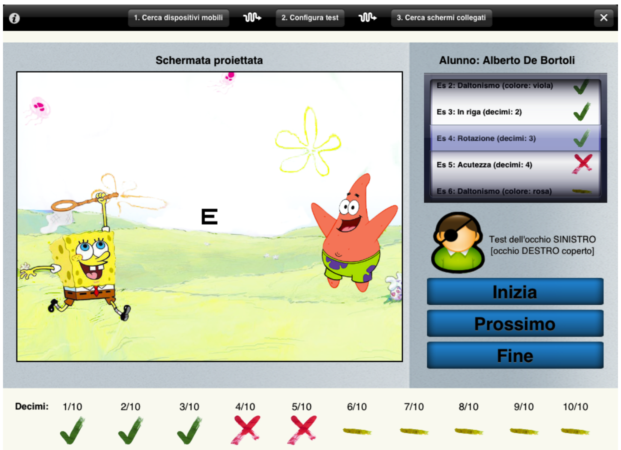


Fig. 9: User interface for the *iPadSight*

Both server and client make use of the typical gesture of touch and tablet devices. Using an iPad as a server is not a common choice, but it represents the best solution in our scenario to reduce space encumbrance. In fact, the server is used both to display the eye test on a visual display, and to interact

[4] We must note here that an Internet connection is required only to sent data to the specialist. This operation can be done later.

with the doctor or teacher to select tests or create new ones (in the case of doctor), or to input children data (name, surname, age, etc.). Since the entire server resides on the iPad, its development has taken into account efficiency issues, since it should be used in a scenario of low resources in term of CPU, network bandwidth and disk space.

6 Resizing Optotypes

To support portability, our system is able to adapt itself to any configuration of the environment, e.g., distance of the external display, fixed monitor resolution etc., to let the user define the best settings depending on the environment constraints and hardware settings. To allow this system customization and get the right results from our tests, it is therefore necessary to calculate the right size for optotypes and images shown by the monitor. In the next section, we provide the theoretical basis and the implementation steps necessary to make this customization possible.

6.1 Theoretical basis

The visual acuity is defined as the amplitude of the angle between two lines connecting the eye to two different points that are sufficiently far from each other to be able to distinguish them. The Snellen optotypes, the first optotypes used to test visual acuity, as well as the “E” chart, used for very young children, are letters that can be inserted into a 5x5 grid (see Figure 10c), where each grid element composes the different letters; Figures 10b and 10a provide examples of the “E” and the Snellen charts used to test visual acuity[5].

According to Snellen definition, “standard vision” is the ability of recognize one of the optotype when it subtends 5 minutes of arc, and thus the person is able to discriminate a single stretch of size 1 minute of arc.

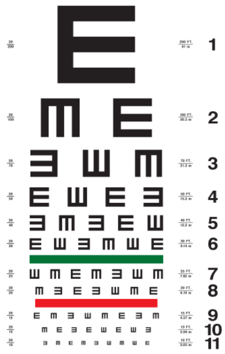
The **visual acuity (VA)** is defined as

$$VA = \frac{D_{effective}}{D_{1'}} \tag{1}$$

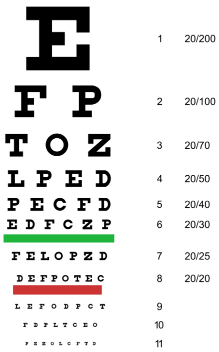
where $D_{effective}$ is the distance at which the test is made and $D_{1'}$ is the distance at which the smallest optotype identified subtends an angle of 1 minute of arc [15].

Considering (1), theoretically it would be sufficiently to use only one single letter and change the distance of the test to get different vision angles, thus keeping fixed the denominator and change only the numerator. This procedure, practically speaking, is difficult since it requires big spaces and distances to

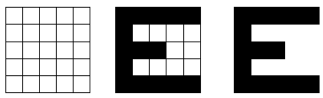
[5] Snellen optotypes which use all the letters require a 10x10 grid, but the calculation is quite the same.



(a) Example of E chart used to test visual acuity



(b) Example of Snellen chart used to test visual acuity



(c) Snellen optotype build with a 5x5 grid

Fig. 10: Examples of the E chart and the Snellen optotypes commonly used by physicians to test visual acuity.

get different values of vision acuity. Moreover, the patient should continuously change the position during the test. Therefore, it is much more convenient to change the size of the letters and keep fixed the distance of the test. Nevertheless, since the formula to calculate the visual acuity with respect to the size of the optotype remains the same, it is necessary to calculate for every optotype at which distance it subtends 5 minute of arc.

To calculate the right size of each optotype we need to define the following notation:

- $H1$: height of the optotype;
- $H2$: height of the single element of the grid;
- D: distance between the patient and the wall;
- α: angle subtended by a single element of the grid;

Using this notation, the following formulas holds:

$$VA = \frac{1}{\alpha} \quad (2)$$

$$\tan(\alpha) = \frac{H2}{D} \quad (3)$$

therefore

$$\alpha = \arctan \frac{H2}{D} \tag{4}$$

One optotype is 5 times an element of the grid, i.e.:

$$5H2 = H1 \tag{5}$$

Since a single optotype subtend a 5 minute of arc, according to the Snellen definition of *Visual Acuity*, combining (2), (4) and (5), we obtain:

$$VA = \frac{1}{\arctan \frac{H1}{5D}} \tag{6}$$

In (6) we consider a minute of arc (see (1)), but since we need to work with degrees and $1' = 60°$, we get:

$$VA = \frac{1}{60 \arctan \frac{H1}{5D}} \tag{7}$$

and

$$H1 = 5D \tan \frac{1}{60\ VA} \tag{8}$$

Using (7), it is possible to calculate the visual acuity of an optotype of any dimension $H1$ and at a given distance D. In the same way, with the inverse formula (8) it is possible to calculate the height of the optotype to create the optotypes charts for every distance. (8) can be rewritten also in the following way:

$$\frac{H1}{5 \tan \frac{1}{60\ VA}} = D \tag{9}$$

We can simplify (9), considering that we are calculating the "normal visual acuity", i. e, when $VA = 10/10 = 1$, and

$$\frac{1}{5 \tan \frac{1}{60}} = 687,5 \tag{10}$$

When $VA \neq 1$, since $\frac{1}{60}$ is a constant value, our formula can be rewritten in the following way:

$$\frac{H1}{5 \tan \frac{1}{60} \tan \frac{1}{VA}} = D \tag{11}$$

Since $VA \in [0.1, 1]$, $tan \frac{1}{VA} \approx \frac{1}{VA}$, from (11) we can approximate in the following way:

$$\frac{H1}{5 \tan(\frac{1}{60}) \frac{1}{VA}} = D \tag{12}$$

Rearranging factors in (12) and substituting the constant value calculated in (10), we obtain:

$$H1 = \frac{D}{687,5\ VA} \tag{13}$$

Using (13), we can calculate the size of an optotype depending on the distance used during the test (D) and the visual acuity that we want to measure VA.

Let us provide some examples. Considering a distance of 3 meters, the height of an optotype to test a normal vision acuity (10/10) is $4,36mm$, according to:

$$\frac{3000mm}{687,5} = 4,36mm \tag{14}$$

while at a distance of 5 meters the height is:

$$\frac{5000mm}{687,5} = 7,27mm \tag{15}$$

If we want to calculate the height of an optotype for a visual acuity of 3/10 at a distance of 3 meters, what we get is:

$$\frac{3000m}{687,5 * \frac{3}{10}} = \frac{3000mm * 10}{687,5 * 3} = 14,54mm \tag{16}$$

6.2 Implementation

To get the final height of the optotype to show on the external display (H), we can use the (13) presented before to calculate the height of each optotype:

$$H = \frac{D}{687{,}5\ VA}$$

where D is the distance of the test and VA is the vision acuity. With this formula, it is possible to get the height of the image of an optotype for every vision acuity and determine the correct height in pixel to use with the screen.

Consider the following problem: we want to draw the optotype to test the vision acuity of 2/10 at a distance of 4 meters; lets calculate the final number of pixels p necessary to draw the optotype knowing the size and the resolution of the display (15' and $1024x768$).

Lets use the following notation:

- A: height of the display
- R: number of pixels of the height of the resolution
- D: distance of the test
- H: height of the optotype
- p: number of pixels for the height of the optotype
- f: number of optotypes that can be drawn together on a screen

In our case, R is equal to 768, while A values $270mm$ (considering a 15' monitor).

Given (13), the height of the optotype is

$$H = \frac{4000mm}{687{,}5 * \frac{2}{10}} = \frac{4000mm * 10}{687{,}5 * 2} = 29,1mm$$

The number of times it is possible to draw the optotype in height is:

$$f = \frac{A}{H} = \frac{270}{29,1} = 9,28 \tag{17}$$

Therefore, the number of pixels used by an optotype is:

$$p = \frac{R}{f} = \frac{768}{9,28} = 82,7 \tag{18}$$

then 83.

Both R, A, D and VA are variables that are managed via software. The setup of this values gives the possibility to use different displays of different sizes and resolution, and and test distance can change, making the system adaptable to the environment settings. To have a practical test and confirmation about the calculus made by the system, before the beginning of the first test the external monitor show a ruler that, in case of right resolution detected by the system, is comparable and equal to a physical one.

7 Tests

In order to evaluate the system, we perform several tests involving teachers and children between 3 and 6 years old. We aim at evaluating both the engagement of the children with the game and if the system is able to test children eyes. The tests have involved 65 children, 40 females and 25 males, from kindergarten "Gianni Rodari" in Mogliano Veneto, Italy. Children are divided into 3 classes, according to age. In the first class (3 years old) there were 9 males and 10 females, in the second class (4 years old) there were 8 males and 13 females and in the third class (5 years old) there were 8 males and 17 females. As we can see, we tested our system with children of different ages to see if and how it is able to adapt, i.e. different interaction methods, and if and how children are engaged while playing the game/test.

We initially presented the game in each classroom, presenting the cartoon characters and the operators who assisted the children during the game. The tests lasted for three days, every day we tested, on average, the eyes of 21 children. We presented the system to the children as a game, but we asked them to pay attention in order to "win" the game, giving correct answers. Two children, 1 male of the second year class and a female of the first year class (out of 63, i.e., only 3%) refuse to play the game.

After the initial presentation, every child played with the game in a separated room. At the end of the game, we asked the child to evaluate the game. During the game the children wore particular glasses with occlusion in one eye. The children played the game initially using the left eye and then the right eye. The exercises performed by the children contains all type of exercises described in this paper. Moreover, we proposed the touch interaction mode to the youngest children, i.e., children belonging to the first class (3-4 years old), and the drag interaction mode to the other two classes.

The test phase provided suggestions for several necessary corrections to improve our system, in particular for the *serious* part of the system. Despite these necessary corrections, discussed in Section 7.1, our system was able to identify visual acuity reduction in two children, as confirmed by their parents. Moreover, this test phase also highlighted how our system is able to engage children in game, and so in the visual acuity tests.

7.1 The *serious* part of the system

Each game session per child was organized with 10 exercises to test visual acuity plus other two tests to test daltonism. For each test, we recorded the answer given by each child, plus the total time required to complete an exercise session. The order of the exercises was the following: acuity (1/10)[6], crowding (2/10), rotation (3/10), acuity (4/10), rotation (5/10), acuity (6/10), rotation (7/10), acuity (8/10), crowding (9/10), acuity (10/10), daltonism (path ♯1),

[6] With $(x/10)$ we want to indicate the visual acuity that we want to test, i.e. the image shown to test 1/10 is bigger that the one to test 10/10.

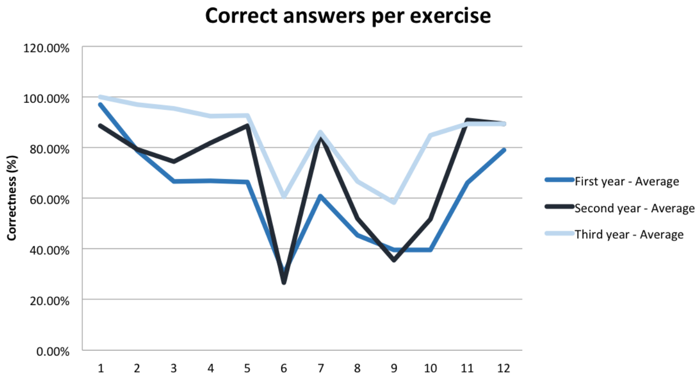


Fig. 11: Percentage of correct answers for each exercise, according to children age.

daltonism (path ♯2). Starting from the answer provided by the children, we analyze the trend of correct answers over the different tests. This data is presented in Figure 11, and lead us to several interesting analysis.

First of all, the tests have shown that the averages of mistakes made by children were higher in the crowding exercises (♯2 and ♯9 in Figure 11), even with big optotypes, while the number of mistakes was lower for other kinds of exercise even with the same (or smaller) size of the optotypes. This means that the problem was in the exercise and not in the children sight. We found that the distance between optotypes in crowding exercises was too small. Following tests with more widely spaced optotypes do not present anymore this anomaly in the average number of mistakes.

Another interesting analysis can be made for exercise number 6. In this acuity test for 6/10, where we used Lea optotypes, we asked the child to distinguish between an apple, an house, a circle and a square, and children gave more wrong answers for this exercise with respect to other exercises which ask to recognize smaller optotypes for higher value of VA, e. g., 8/10 or 10/10. Since the optotypes were too small, many children made confusion, mixing in particular the apple with the circle and the house with the square. The children do not make the same mistakes using the “E” or the Snellen chart for the same value of VA. Besides this, the high number of errors was also generated from the low definition of the screen, i.e. $1024x768$ pixels, therefore an higher resolution monitor could decrease problems in misunderstanding. More in general, what we found is that the Lea optotypes are not suitable to assess children visual acuity equal or superior to 6/10, since when the optotypes are too small, the “E” or the Snellen charts should be preferred.

We also notice that some types of exercise has a insufficient value of contrast between the color of the optotype (black) and the color of the background (sky blue). We then modify the background color to white, increasing brightness and contrast, according to the suggestion of ophthalmologist involved in the project.

Moreover, although the Lea symbols and the tumbling “E” are extremely easy and suitable for preschool children, the tests highlight a big limitation. In both cases, the total number of possible answers are limited to four (the total number of Lea symbols, up, down, right and left for the “E”), so the probability for a child to correctly answer to a test randomly choosing between one of the four symbols is 25%, which rises to 33% after the first, wrong, answer. Therefore, we decided to introduce, in addition to the Lea symbols, also the alphabetical letters. Moving from 4 different choices to 26 (the complete English alphabet), the probability of a correct randomly chosen answer decreases to 3,85%. However, the introduction of a big number of alternatives requires to redesign the interface for the children, as discussed in Section 4.3.

To evaluate if our system is able to recognize visual acuity reduction in children, we asked an ophthalmologist to use the data provided by our system to evaluate visual acuity of the children and to identify particular diseases. For example, a child who shows a significant difference between visual acuity of each single eye has, potentially, an amblyopic eye. Using our data, the ophthalmologist was able to identify visual acuity reduction in four of the tested children, amblyopia was identified in two of them. We ask the parents of these children to have a test with an ophthalmologist or to provide medical records from other doctors: three of them agree, and the results obtain with our system were confirmed in two cases from external medical records (one of them confirm amblyopia) where other doctors reach the same conclusion using actual and standard visual acuity test. In the third case, the test was repeated with the white background and the child was able to answer to all the exercise. This can be clearly considered a big result, since it shows that it is possible to reach the same conclusion about visual acuity of children using our system instead of the standard exercises. The differences with respect to the standard tests is that now children are engaged (for a deeper analysis of this aspect see Section 7.2), tests can be longer and so provide more accurate and precise data.

As already discussed in Section 4.2, these tests also showed that the initial exercise for daltonism was not correct. We showed a chameleon on the monitor and we asked the children to choose between four chameleons on the iPod screen. Unfortunately, colors used to fill the chameleon were rendered in a different way in the monitor and on the iPod screen, and two children were not able to answer since they perceived all the offered possibilities as different from the color rendered on the monitor. Using printed Ishihara plates, both the children gave correct answer. Therefore, we change the exercise for daltonism using colored Ishihara plates on the external monitor, and a black and white representation of the paths on the iPod monitor.

7.2 The *game* part of the system

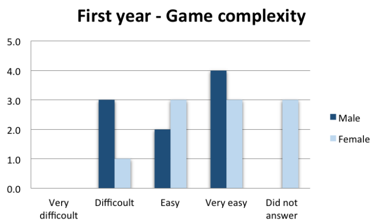
To evaluate if the children liked the game, after each test, i.e. a set of twelve exercises for visual acuity and daltonism, we asked each child to provide us an evaluation of the game and about their experience. Children of the second and third year (aged between 4 and 6) were able to use the dragging interaction method. Children of the first year instead were able to use only the touch interaction method.

The first question we provided to the child was about the complexity of the game. This evaluation is important since if the game are perceived as too much complex by the child, he/she could decide to stop to perform the exercises because the game is requiring too much strain from him/her or decide to give random answers only to quickly complete the game. The results of this question are reported in Figure 12, divided per year (a-c) and considering all the children (d). As we can see, the data provided follows a good distribution over all the years. In general, Figure 12d shows that the most preferred answers were "Easy" and "Very Easy", meaning that the games were correctly designed and were suitable for all the ages.

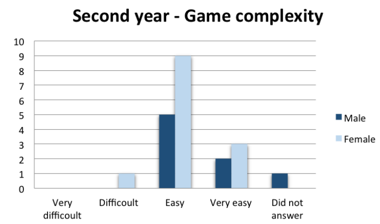
Considering the data acquired per each year, we can see how data follows an expected trend. Since the same game were used for all the children that belongs to three different classrooms and ages, it is clear that the perceived difficulty of the game cannot be the same. This difference in the perceived difficulty was expected and, therefore, correct. Considering the older children (third year, 5-6 years old, see Figure 12c) the most commons answer provided are "Very Easy" and "Easy" (with no "Difficult" answers). Only one child gave "Very Difficult" as answer, but we want to pointy out that he was the first child to play with the game, and he was agitated and clearly in anxiety for this test.

Considering the first year classroom (3 years old, see Figure 12a), some children rated our games as "Difficult". In the middle, rates from children of the second year contains an higher number of "Easy" answers with respect with the "Very Easy" ones (see Figure 12b). Again, since the games were the same for each child of all the ages, this data trend is absolutely encouraging and shows how our games were correctly designed from a difficulty point of view.

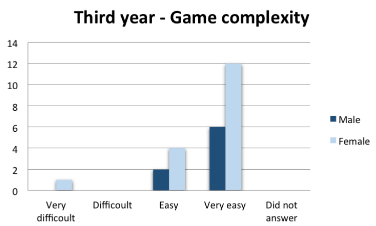
At the end of the test we also ask children to rate the game appreciation. Each child had to choose between the answer "Very Much", "Much", "Neutral", "Not so much" and "No", using a scaled build using five different smiling (or sad) faces. This evaluation was necessary to understand if the games were sufficiently engaging and if they could be use to keep the attention of the child during the exercises, thus having more precise and useful answers. During the submission of the questionnaire we notice that children are able to distinguish between a sad and an happy face, but their degree of attendance decrease when they have to discriminate between an happy and an happier face. For this reason, and to present more statistically significant data, we grouped the initial 5 possibilities in 3 for clarity sake: 'Very Much" and "Much" were grouped



(a) Game complexity evaluation, first year children.



(b) Game complexity evaluation, second year children.



(c) Game complexity evaluation, third year children.

(d) Game complexity evaluation, all children.

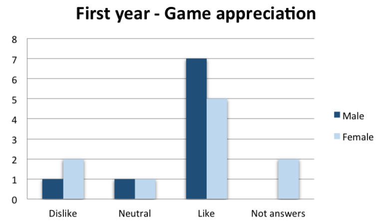
Fig. 12: Evaluation of the complexity of the games.

into "Like", "Not so much" and "No" into "Dislike" and "Neutral" remains the same. The results of this question are provided in Figure 13d, and divided per classroom in Figures 13a, 13b 13c.

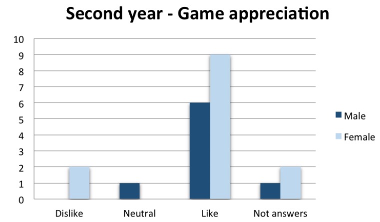
As we can see, the collected data are clearly positive and encouraging. In general, 75% (49 over 65) of the children chose "Like" as answer, while only about 7% chose the "Neutral" one and only another 7% did not like the game. About 9% decided to not answer. As we can see, the game were well accepted by the child, meaning that our system could be used to engage them and to perform an eye test while playing. In this case, we do not observe many modifications in the acquired data between the three different classrooms, meaning that the engagement was good with all the tested children.

7.3 Tests execution time

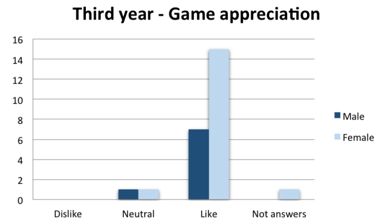
For every child we have even measured the execution time; the averages are reported in Table 1. Since the test begun with the left eye, the time necessary to complete the exercises with this eye was higher with respect to the right eye, meaning that children spent more time understanding how to play. Moreover children of the first year used the touch interaction which allows quicker answers.



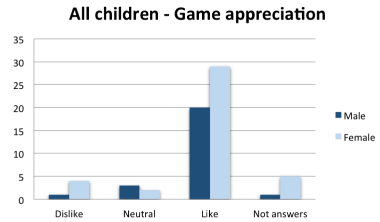
(a) Game appreciation evaluation, first year children.



(b) Game appreciation evaluation, second year children.



(c) Game appreciation evaluation, third year children.



(d) Game appreciation evaluation, all children.

Fig. 13: Games appreciation evaluation.

On average, we need only 8 minutes to complete the assessment of each child. Usually a normal visual acuity test requires between 15 and 20 minutes, with the child's parents that constantly help the doctor to maintain the child's attention. The low execution time has been positively evaluated even by teachers, that reported how an audio metric test made in the same school took several months, interfering with the didactic work.

	3 years old	**4 years old**	**5 years old**
First eye (Left)	4'27	5'13	3'42
Second eye (Right)	3'02	3'06	3'15
Total time	**7'29**	**8'19**	**6'57**

Table 1: Execution times for the test

8 Conclusion

To maintain children attention during medical tests is a big challenge for doctors, in particular when the task is boring and last for a long interval of time. Collaboration, or non collaboration, of children may deeply affect the precision of their answers, therefore the correctness of the final assessment and diagnosis. This is particularly true for visual acuity tests.

In this paper we presented *PlayWithEyes*, a *serious game* designed to help eyes test for very young children. *PlayWithEyes* can be used for screening children in kindergartens, aged from 3 to 6 years old, but it can also be used in doctor's surgeries with younger children.

First of all, thanks to the use of mobile technologies, we design a *portable* system which is able to adapt itself to any situation, in term of availability of the Internet connection, size of the external monitor and distance of the children from the monitor. Moreover, the system provides a touch interface both for children and doctors (or teachers) since the use of this technology improves the accessibility and usability of interfaces for non-expert users. The user interface provides two interaction mode to adapt its level of difficulty to different ages of children.

PlayWithEyes has been tested with 65 children, and the results of the tests and of the following interviews with children have shown great results. Data about visual acuity obtained of our tests go through a further analysis by an ophthalmologist who was able to identify at least two children with visual acuity problems which was confirmed by medical records obtained by other doctors with the standard visual acuity tests. Therefore, we can argue that the precision of the results obtained using our system are comparable to the ones obtained with standard tests. But the tests also shown that the use of a *serious game* can dramatically reduce the length of the test (8 minutes against 15-20 minutes) and easily engage the children thus improving the precision of their answers.

The results of the interviews with the children showed that we were able to engage 97% of the them, without distinction of age and sex, therefore interaction methods are suitable for all the ages. Moreover, the use of touch interface greatly help usability of the system, since the perceived difficulty followed the correct trend, being easier for the older children and a bit more difficult (but not too much difficult) for the younger one.

Survey of background and related works shows that this is the first time that a *serious game* has been used for a visual assessment and, more in general, for an assessment, since this paradigm is usually used for rehabilitation exercises, but results obtained are encouraging.

Future works will be devoted to adapt the game to children with disability, e.g., *Cerebral Visual Impairment (CVI)*, a disability that entail a visual deficit, due to a brain damage. Children affected by CVI have strong preference for colors, need to move an object to be able to see it and have difficulties to understand complex images. For these reasons, it is often difficult to obtain a correct assessment for these children.

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