Games, Assessment and Rehabilitation: When Serious Games Support Cognitive Development in Children with Cerebral Visual Impairment

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Abstract. In this paper, we present a study on the use of serious games in the assessment and rehabilitation of children with Cerebral Visual Impairment (CVI). Moving objects support vision and processing the information conveyed in children with CVI; they also find it easier to deal with more simple images. Our serious games help them keeping focused on the exercise by using touch interface, the game paradigm and cartoon characters. The paper reports lesson learned from data collected in a user study to highlight the high potential of using these games also in the rehabilitation process, which brings us to develop the games also in a mobile platform to allow children train the skill at home, i.e., more intensively and in a familiar environment.

Keywords: Serious games based assessment and rehabilitation
CVI

1 Introduction

Cerebral Visual Impairment (CVI), also known as Cortical Visual Impairment, is a disability that entails a visual deficit, due to a brain damage (Roman-Lantzy 2007). People with CVI are not able to see an object if this is not moving. Moreover, they have a reduced ocular field and ocular delay, find difficult to understand complex images and they are not able to see and touch an object at the same time. Child affected by this disability can experience different levels of these difficulties.

Many studies have shown that Serious Games can help children affected by disabilities since they help to obtain their attention and to protract the training session

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since they have fun (Gaggi and Ciman 2016; Gaggi et al. 2017). In Ciman et al. (2013) and Gaggi et al. (2016) we described two serious games designed to train children affected by CVI. The system allows tracking both eyes movements, thanks to an integrated eye-tracker module, and users' touch interaction. *CathMe!* is a Serious Game which asks children to follow a cartoon character chosen according to child's preferences by both looking to it and touching it. *HelpMe!* asks users to help Santa Claus's assistant classify presents according to their category. Each level of the game has a different set of target semantic category, e.g., "musical instruments", "clothes for dolls", "cars" and so on; each of them is composed by a set of different object images belonging to the specific semantic category. Children are required to recognize among intruders objects belonging to the target category announced by the speaker.

We initially tested the system with 28 children from kindergarten, aged from 3 to 6 years old, who did not experience disability. This initial testing confirmed the acceptability of the system, and the confidence of the children while playing with it. Information about performance in children with normal sight level were also reported in Gaggi et al. (2016) and were used as base line in this paper when analyzing performance in children with CVI. A second test was conducted by asking 19 children affected by CVI to play with our games. In this paper, we present an example of a specific pattern emerged with one participant to highlight the high potential use of these games with the results obtained with a four years old child.

The paper is organized as follows: Sect. 2 describes performance and, more specifically in Sect. 2.1, results obtained by one of the study participants. In Sect. 3 we describe the implementation of the games in the mobile platform to allow children to train at home. Finally, Sect. 4 presents conclusions and directions for future research studies.

2 Strengths and Rehabilitation Perspectives of Serious Games Assessment Tools: The Example of a 4 Years Old Child with Marked CVI

As already mentioned, the test phase involved 19 children affected by CVI. Children involved were aged between 4 and 9 years old, 13 of them were females, 5 were males. Unfortunately, not all the data collected during the training sessions are significant to present for several different reasons: first, some children with CVI are unable to move their hands in a coordinated way, so they are not able to keep the finger touching the screen along the activity proposed; second, sometimes the eye-tracker was not able to collect data due to the child difficulty in maintaining the head in the correct position, or because of too many head's movements; finally, the variability of children's age with respect to data available from children without CVI limit the comparison with peers without CVI. For these reasons, in order to highlight the potential of this type of assessment, we decided to provide the analysis of a single profile as an example, presenting changes in her performance in both the activities proposed and comparing her responses with data currently available from age-matched peers. Our analysis highlights a series of information emerging from the performance of Hope, a 4 years old girl with a marked CVI and residual vision who was able to play for the full session.

Hope has been proposed our serious games, which consist in different interactive situations through which the typical development and assessment of visual abilities in children is conducted. The goal of the proposed activities was twofold, i.e., to assess the level of processing of the visual information available to Hope, and to analyze the learning potential and retention of visual information.

In particular the proposed tasks were:

A. *Where is Nemo going?* Hope practiced with movements in the visual field. She was asked to look to the goldfish Nemo, which will appear on the screen. This game was used to calibrate the system.
B. *CatchMe! Where is Peppa/George going?* (Fig. 1, left) Hope have to follow a cartoon character chosen according to participant gender, which was moving on the screen. The task goal is to orient her attention.
C. *HelpMe! The Santa Claus's assistant* (Fig. 1, right). She was asked to help Santa Claus in a long-lasting task, i.e., to prepare in advance the sack of Christmas presents. Pictures of objects belonging to three different target semantic categories (animals, vehicles and clothing) are used together with objects belonging to other categories (intruders). All pictures take into account the age of acquisition and the organization of the children semantic lexicon at her age. Hope was then required to orient the attention and focus on the object, to discriminate between target images (i.e., images that belong to the target category) and intruders, and make a cognitive decision putting the target object into Santa Claus' sack, and throwing out of the screen the other ones. If she failed to discriminate one of the images of a particular set of pictures, she was asked to repeat the actions. After three failures in the same level, the game moves to the next sequence.

Fig. 1. *CatchMe!* (left) and *HelpMe!* (right) games.

2.1 Results

Hope performance is described with respect to changes occurring along the execution and age matched peers in order to highlight strengths and vulnerabilities. While game

Were is Nemo going? was used to develop familiarity with the situation and calibrate the system, eye movements, accuracy of the answer and reaction times were collected and analyzed respectively for games *CatchMe!* and *HelpMe!*.

CatchMe! Visuo-motor coordination game following a visual stimulus moving on the screen

The goals set with this game were twofold. First of all it aimed at describing the basic level of the target skill, that is visuo-motor coordination; secondly at providing information on the learning potential of the participant in order to make more effective subsequent rehabilitation decisions. To accomplish the second goal the game was proposed a second time and some manipulations were introduced (Sgaramella 2016).

Figure 2 represents the Euclidean distance between the center of the image presented on the screen and, respectively, the position of Hope's eye (Gaze) and the position of the finger on the screen (Touch). The green solid line represents the position of the Target picture on the screen, which however changes over the task. The picture provides a temporal description of Hope performance occurring across the activity and highlights the direction of changes occurring for an interval of time of 30 s. Along the time interval described in the graph, the Touch index results in an almost stable line with a more marked reduction in the last portion of the considered time interval. At the same time, the picture shows a decrease in the distance between the point of the actual touch and the position of the picture on the screen, with the gap passing from more than 1000 pixels to an interval comprised between 500 and 250 pixels. Hope's finger is then closer and closer to the picture[1], thus suggesting a systematic trend toward a more accurate performance and a learning process activated in a visuo-motor task.

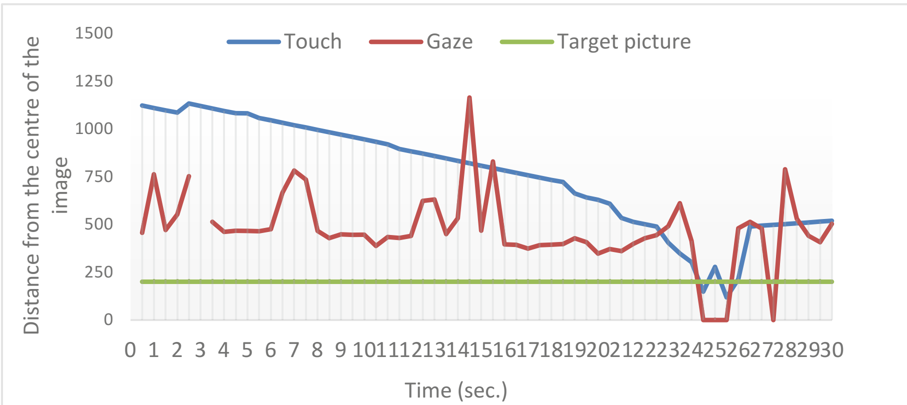

Fig. 2. Delta for Touch and Gaze with respect to the target picture in a portion of task execution

[1] Consider that the distance is computed from the center of the picture, but the picture itself has a dimension, which depends on the user's setting, and in this case is 200 × 400 pixels.

Sustaining learning with repeated task execution and a higher complexity
Hope was then required to execute the task for a second time. In this case, starting from a higher performance gained in the first execution, she was presented the target item in different portion of the screen, hence requiring her to orient her visual attention to different portions of the visual field.

In Fig. 3, which is focused on the gaze analysis, the distance between the Gaze line and the solid line representing the Target image was rapidly and markedly decreasing along the time interval described. The finger pointing was consistently close to the actual position of the object moving on the screen. Therefore, in the second trial, once she refreshed the task, her performance improved in accuracy and persisted at very accurate level thus suggesting that continuing with the training the performance could be more accurate and stable displaying her learning potential in focusing attention and in coordinating the hand movements in order to accomplish the task.

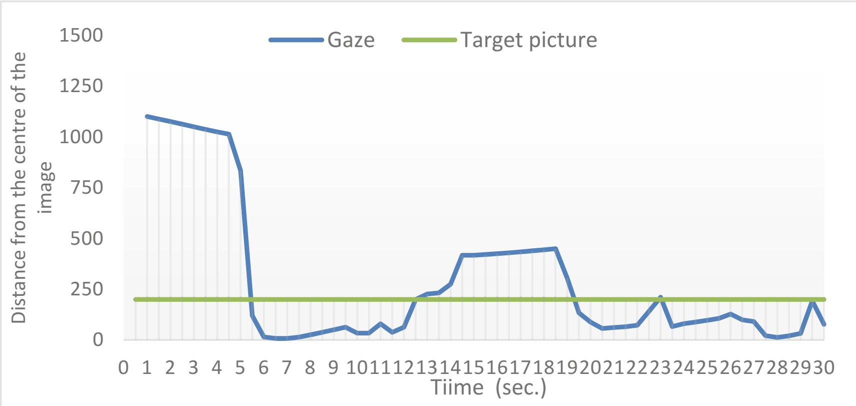

Fig. 3. Delta for Gaze with respect to the target picture in a portion of the repeated task execution

***HelpMe!* A controlled access to complex visual information in a visual decision making task**
Given the relevance of the processes investigated in the cognitive development of children and the relevance for school inclusion, cognitive decision making relying on more complex visual information is introduced. Both accuracy of visual attention performance and decisions made are then analyzed.

Accuracy in visual semantic decision making
In this game, Hope was required to decide on the sematic category to which the object represented on the screen belonged to. Her performance was 77% of correct answers in the first presentation of the items. However, she was capable of reaching full correct performance in the second execution of the task.

Figure 4 shows the details about her performance as compared to age matched peers and described in terms of standard deviation from mean level obtained with 28 children in a previous study (Gaggi et al. 2016). The decision time refers to the time needed to take a Yes/No decision about the semantic category of the object appearing on the screen, e.g., the time that passes between the image arrives on the screen and the first interaction of the child with that image to move to the right place; the completion time refers instead to the time needed to move the object from the position where it has appeared to the Santa's sack, or to put it in a corner.

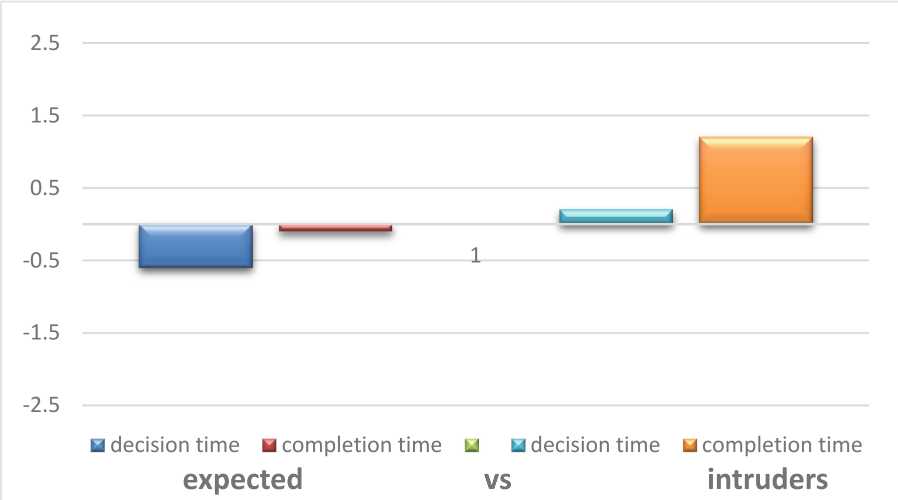

Fig. 4. Hope reaction times expressed as standard deviation from age matched peers in the decision and completion task for both expected items and semantic intruders

The game highlights Hope ability in selecting the appropriate object, maintaining the gaze to an attentional level adequate to keep track of the movement until she reaches the appropriate destination. The time required both to decide and to complete the task which was expressed in milliseconds, is within the normal age range insofar it falls within ±1.5 standard deviation. This applies both when the showed picture belongs to the category announced by the speaker and when it is an intruder. Finally, deciding that an object is an intruder, that it does not belong to the semantic category, is a more complex process and thus requires a longer time.

Category specific decision making

Objects proposed to Hope belonged to different semantic categories. Her specific skill in making decision about objects from different categories, also characterized by different levels of internal visual structure (e.g., an animal or a car) was then analyzed. Additionally, her answers to both expected items and intruders, requiring a specific decisional ability, were separately analyzed. Figure 5 shows Hope performance as compared to age matched peers.

As shown in the figure, items from different categories, with different internal structure, showed a similar level of difficulty for Hope, with the performance in decision making falling within normal age range, either for expected and intruders, that is with unexpected items.

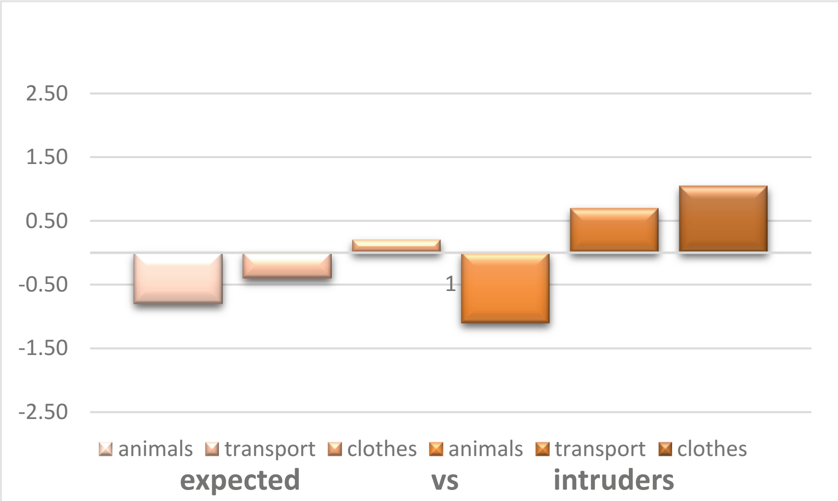

Fig. 5. Hope reaction times expressed as standard deviation from times obtained by age matched peers in the decision making task for both expected items and semantic intruders

Completion time for specific semantic categories
The time needed to complete the task, for different semantic categories was then analyzed.

As shown in Fig. 6, Hope's performance was within normal age range with expected items, i.e., objects congruent with the category announced by the speaker. With intruders of different categories, the time required to complete the task was significantly longer thus suggesting a longer execution time but only when it deals with a structurally more complex category such as means of transportation, although items were characterized by the same familiarity level and age of acquisition as a semantic category.

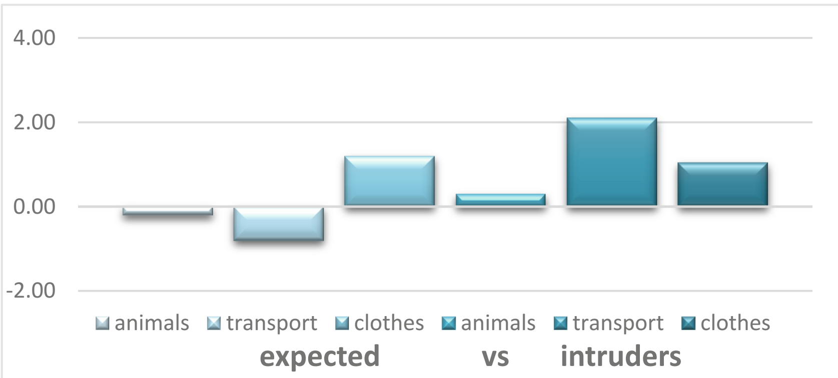

Fig. 6. Hope reaction times expressed as standard deviation from times obtained by age matched peers in the completion task for both expected items and semantic intruders

Summary of results
As far as Hope is concerned, data collected with these games highlighted her visual attention and visuo-coordination skills but also visual object recognition and visuo-semantic decision making. Additionally, these games have been useful in describing the improvement in performance during the task, as well as her ability to follow a moving object keeping her gaze coordinated with the finger till the object reaches the final appropriate destination. Indexes used were then useful in tracking learning development in terms of both accuracy and speed of processing, which is relevant in terms of rehabilitation choices and for future perspectives.

From a methodological level, the assessment described supports the adequacy of the tools, at least when working with 4 to 6 years old children with CVI and residual vision, either in the assessment and in supporting the development of decision making skills. It provides guidelines for subsequent applications of the tools, that is: proposing repeated execution of the tasks, looking at both accuracy and reaction times, manipulating complexity either in visual scanning of the screen and in complexity of the visual structure of the pictures used.

3 Going Mobile for Ecological Intensive Rehabilitation/Practice

As we already presented in Sect. 2, results from the assessment of specific visual skills in a child with CVI, when tested with our system, were useful both in assessing basic skills and in analyzing learning potential and persistence of learned tasks related to the ability of recognizing and following object moving on the screen and, more demanding, on taking cognitive decisions on the incoming materials.

Considering that the described results are observed in a test that lasted for a very short interval of time, about 15 min, the possibility of using the game for longer time intervals becomes very interesting and more appealing. A further step is then implementing a solution, which might allow children and their parents to have the opportunity of practicing these activities in a more extended, and at the same time intensive way. The idea is to give the children the possibility of using the game at home, thus giving the possibility of practicing the more they can, whenever they want, with the support of their parents, and in a more comfortable and familiar environment. Since the games are proved to be engaging, either the duration of the training session and the complexity can be set and modified when needed to a more complex and demanding level of analysis thus providing a personalized learning.

For this reason, we implement a mobile version of our games *CatchMe!* and *HelpMe!*, to make them available to children to play at home, maybe following a program provided by their doctor.

One of the problems which is necessary to address when developing applications for mobile users is related to market fragmentation. Despite the low number of children affected by CVI, supporting only a particular device/operating system could strongly reduce the number of potential users, hence reducing the possible benefits of our application. For this reason, the best approach for developing is to use a cross-platform framework (Ciman and Gaggi 2017), that let developers build only one application using the framework specific language, and deploy this application to multiple mobile operating systems, e.g., iOS, Android, Windows Phone, etc. Since the system was initially developed as a web application, the best candidate solution was Apache Cordova framework[2], which allows using a webkit engine to wrap a web application into a mobile hybrid application that can be installed on mobile platforms.

Since we cannot assume that all children have a smartphone or a tablet and since they surely do not have an eye-tracker at home, when they play at home we can collect data about touch but not about gaze.

The mobile application, after requesting for username and password defined with the doctor when the child was added to the system, let the child decide with which game he/she wants to play, i.e., *CatchMe!* or *HelpMe!* Then, the application downloads the game settings for the child, that could be adapted by the doctor after having analyzed the performances of the child. Then while the child is playing the game, the application records information about the touches and the interaction of the child with the game, and stores this data locally in the memory of the application. Only at the end of the game session, or when an internet connection is available, the application will ask to upload the data on the server. The uploaded data contain information about the game settings used during the game played by the child, e.g., screen resolution, images size, etc., the interactions of the child with the screen and the game and, in case of the *HelpMe!* game, the number of correct and incorrect answers. For the *CatchMe!* game, once all the data upload has been completed, the server will analyze interactions and image's movements to provide an evaluation of the touch performances of the child.

Once uploaded, the doctor is able to analyze data and performance of each child for the specific exercise carried out; he/she can also modify settings and tasks to make them more suitable for further progresses of the child and/or taking into account the difficulties encountered by the child while exercising at home.

4 Conclusions

In this paper, we have analyzed the results obtained using our serious games for the assessment and rehabilitation of children affected by CVI. Combining both basic visual search task with more complex tasks requiring attention and cognitive processes, such as decision making, allows a 'whole child' evaluation and helps identifying all areas of strengths and difficulties, a direction advocated by neuropediatrics as crucial for fostering the development of children with CVI.

By supporting the assessment of preserved skills, the system supports also a personalized learning for children with CVI, that is providing a condition in which the pace of learning, the level of difficulty and the instructional approach are optimized for the needs of each learner. In addition, the activities implemented in the system are meaningful and familiar to learners thus driving their attention. Identifying ocular, oculomotor, perceptual and/or visuo-cognitive preserved skills is, in fact, essential for

[2] https://phonegap.com/.

CVI children in order to apply specific habilitation programs and increase their potentials for inclusion and participation.

Despite the difficulty in collecting data that can be compared with normally developing children, the analysis of data collected with a four year old child has shown an improvement in the performance even with a very short training session (only 15 min). Although at the moment supported by a single user, the system is promising for implementing a personalized learning. Further experimentation is also needed for instance with gradual inclusion of additional features. The mobile version of our serious game, which we implemented, can be effective in allowing children to train themselves at home, for longer interval of time. Moreover, the system implemented provides a mechanism for recording learning achievements and communication between the family and the professionals. The pace and learning development curve can provide the basic information for identifying strategies for everyday life both at home with family members and for teachers in the educational settings.

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