Assessment and Assisted Training Software for ADHD*

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Abstract. Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder; prevalence ranges between 3%-5% among school-aged children. Cognitive deficits associated with ADHD are related to a malfunctioning of executive functions (EF), high-level mental processes that allow self-regulation, behavior control and organization. Negative outcomes, especially in academic performance and mood states, are frequent.
There is evidence of the potential of new technologies and eHealth interventions for children with ADHD. The present work introduces the design of a software, available for tablets, aimed at empowering EF of school-aged children with ADHD. Particularly EF are: attention, working memory, inhibition, cognitive flexibility and planning.
The software has been developed with Unity cross-platform game engine and is divided into 3 main areas: user profile, test and training. Test area contains an EF evaluation session that carries out indications on functions to be further strengthened. Training exercises of EF are gamified to enhance children motivation; furthermore, they are calibrated through an intelligent tutoring system (ITS). In addition, it is possible to collect accurate and automatic data of the individual performance and, then, provide the most useful strategy to help the child. All features are described.
Test standardization is currently in progress. In conclusion, the main purpose is to increasingly adapt the training to the real needs of the children and make it as much ecological as possible for the transfer of acquired skills to everyday life, above all to learning contexts as school.

Keywords: ADHD, executive functions, assessment, training, software, ITS

1 Introduction

The present paper introduces a software, available for mobile devices, aimed at empowering executive functions of school-aged children with ADHD. The software is at a first stage and there are no specific results, however a detailed description of the tool and a standardization design is provided.

1.1 Attention Deficit Hyperactivity Disorder and Executive Functions

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder that shows onset at about 6-7 years age [1] [2]. In 2016, it was estimated that 6.1 million children in the US between 2 and 17 years of age (9.4%) were diagnosed with an ADHD condition [3], instead, worldwide, the prevalence of ADHD ranges between 3% and 5% among school-aged children [4].

An ADHD condition leads to a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development. ADHD symptoms may present with a combined manifestation of inattention and hyperactivity/impulsivity, with predominant inattention or predominant hyperactivity/impulsivity [1] [5].

The cognitive deficits associated with ADHD are related to a malfunctioning of executive functions [6][7][8]. The executive functions (EF) are high-level mental processes supported by structures present in the frontal lobes of the cerebral cortex, particularly prefrontal cortex [9]. EF allow self-regulation, control and organization of behavior through the representation and internal processing of information. This self-regulation guides the direction of behavior towards future goals and the ability to restore behavior if interrupted.

A review of the literature [9] [10] shows that the main executive functions are: attentional control, inhibition, cognitive flexibility, planning, working memory and information processing. Therefore, children with ADHD, have difficulties in maintaining attention, monitoring or regulating performance; they tend to be impulsive, fail to complete tasks, commit procedural mistakes. Moreover, they struggle with perseveration and mental inflexibility, planning and organizational problems, poor reasoning ability, difficulties generating and/or implementing strategies, poor utilization of feedback, and reduced working memory.

Scientific studies demonstrate that the risk of negative outcomes is very high in children with ADHD [11]. Worse academic performance was found in ADHD individuals, compared to healthy people: they often failed a grade or have been suspended, expelled or have dropped out of school. Clearly, children with ADHD present academic difficulties due to an inability to use their cognitive and executive resources [12], particularly of working memory, learning strategies and inhibiting irrelevant information. Furthermore, early onset executive functions deficits are relatively stable over time into young adult years, both in females and males [13] [14]. Nevertheless, literature supports evidence of comorbidity of ADHD condition with conduct disorder, oppositional defiant disorder, mood disorders, anxiety disorders [15].

Compared with one treatment, combined treatment is superior in improving ADHD symptoms, according to parents' and teachers' ratings [16]. The combination of the pharmacological treatment with the psychological intervention offers some advantages compared to the exclusively pharmacological treatment as it allows to use smaller doses of medicine [17].

1.2 New technologies for disability

There is evidence of the potential of new technologies and eHealth interventions for children with neurodevelopmental disorders, including ADHD [18] [19] [20]. Smartphones, tablets and PCs are always more affordable and flexible, and they can deliver care to children in a novel way. These assistive technologies can support software and apps that help children with ADHD to keep track of time, build an activities calendar to remind them and train their cognitive processes (most of all working memory). New technologies are attractive for children and easy to use.

A strength point of new technologies is the possibility of collecting accurate data, to integrate with others, that could help clinicians in determining diagnosis and improve treatment procedures [21]. The implementation of a system that automatically tracks patterns during training can ensure a high-level evaluation of the training progress.

An additional feature of new technologies is the gamification, a set of rules borrowed from the world of videogames, which have the objective of applying playful mechanics to activities that do not directly deal with the game; in this way it is possible to stimulate and consolidate active interest of the users involved [22]. Whether the goal is cognitive abilities learning by children with attentional difficulties, is crucial to successfully engage them with game design elements. If children lack motivation and attention cannot be sustained, training is useless, and have a negative impact on the quality of data collected.

Since the tutoring tasks of supporting specialized learning activities have been digitized in special IT systems, called ITS - Intelligent Tutoring System, it is possible to adapt the training of specific cognitive functions to people's needs [23] [24] [25] [26]. The peculiarity of these systems are specific computer algorithms able to manage each user in a different way from the other, creating a user model able to trace the history of the individual learning processes [27].

An intelligent system, during training, allows to compare the user's performance with the correct one implemented in the system; to interpret the specific performance provided by the user by formulating hypotheses on his basic knowledge and skills; to translate information from the internal system to the user, and vice versa, through specific and appropriate interfaces.

Furthermore, it is possible to calibrate the strategies that must be used to teach individual users (in terms of timing, speed, feedback, etc.) because the system can adapt flexibly to user behavior. ITS use strategies as the variations in feedback and prompts based on users' learning behaviors; the frequency of prompting by an intelligent tutor has a significant effect to promote learning [24]. An ITS can automatically decide if the individual needs a feedback or a prompt, and, whether it is needed, what type and procedure of support fit the best with the level of difficulty experienced.

Next paragraph will describe a software created for training executive functions of children with ADHD.

2 Software's features

As previously highlighted, children with a condition of ADHD show cognitive deficits related to a malfunctioning of executive functions. The present work introduces the design of a software aimed at empowering executive functions of children with ADHD: since the use of portable touch devices by children with disabilities is rapidly growing, the purpose is to make the most of the potential of these devices, to build an integrated tool based on scientific studies and clinician's knowledge about Attention Deficit Hyperactivity Disorder. After a careful research and analysis of the literature on ADHD and executive functions in the clinical, diagnostic and intervention fields, we developed a design of an application available for tablets. Particularly, target users of this software are school-aged children, from 6 years to 11 years. The tool is intended for use by children under the supervision of a clinician or a therapist.

Most of the existing software devoted to children with a condition of attention deficit hyperactivity disorder are focused only on training of cognitive functions, especially on working memory training [28]. Clearly, the assessment of executive functions could be useful to help to identify children who are likely to have ADHD [28]. The inclusion of a cognitive and neuropsychological assessment of executive functions in clinical contexts offers the opportunity to develop a more focused intervention on the main difficulties of children, since it can be useful to describe better the nature and degree of cognitive effort a child is experiencing.

The novelty aspect of this tool concerns both the evaluation phase, which allows to have an initial description of the child's executive functions and provides indications on the specific areas to be strengthened, a lacking aspect in literature, and the wide spectrum of abilities that the training phase has goal to strengthen, as well as a smart tutoring system during training. Moreover, the tool will be equipped with a data collection system and internal report which will provide a tracking of the child's progress, also available for caregivers.

The application has been developed with Unity cross-platform game engine (by Unity Technologies) [29]. The first screen of the software is divided into 3 main areas: user profile, test and training. Moreover, this section contains a button which allows access to the management and settings area. Each section is described below.

2.1 Management and settings

The settings area allows to adjust the features of the software according to the personal needs of each user, in a simple and intuitive way.

Firstly, it is possible to choose two versions of the software, because, in some cases, sessions of test or training have been differentiated based on two age groups: children of 6-8 years and children of 9-11 years. In our opinion, differences between ages must be considered, so 6-8-year-olds children will start the assessment of some EF from a lower level than 9-11-year-olds children because they are assumed to have not achieved some necessary prerequisites for that level (such as reading skills).

Furthermore, for each task or exercise it is also possible to adjust the time limit, in seconds, and to increase or decrease the time interval between all the task screens, in seconds as well [Fig. 1].

Since the software is provided by a voice assistant that guides the user during the performance of the tasks, in the settings area it is possible to select the preferred voice, one that uses a voice synthesis (text-to-speech, TTS) and one that is a real voice recorded by humans.

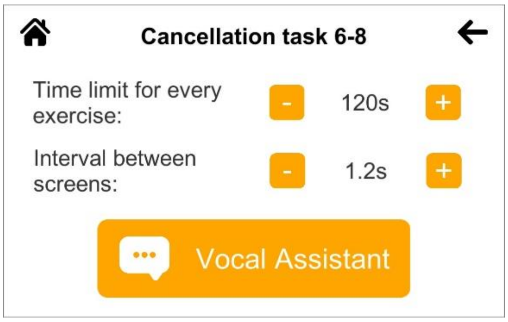

Fig. 1. An example of the Cancellation Task's settings interface

2.2 User profile

The user profile is an area that contains the child's personal data: name, age and photo. Secondly, the profile provides information on scores obtained in the test phase, outlining a starting profile of the user, but also training progress, indications on areas to be further enhanced, comparisons between training phases over time.

These information are shown through an interface that is easy to understand for parents and caregivers. It is also possible to create multiple profiles in the same device, so that it is possible to use a single instrument with several children.

2.3 Assessment

The testing section contains an evaluation session that allows to establish the starting point of the child and gives indications on the areas to be further strengthened. This phase can be repeated later to re-evaluate the child after a training period. Since it is an evaluation phase, no feedback is given to the child during that; moreover, the graphic is pleasant but essential to ensure that the assessment is not affected by distractions.

The exercises are presented to the user in random order. At the end of each exercise, a button will appear with the word "Continue" to proceed to the next exercise. If during an exercise it is necessary to interrupt the test, it is possible for the clinician or the therapist to make a gesture (by dragging the finger from the left to the right side of the screen at the top) and press the red button that will appear at the end of the drag at the top right; the screen then become darker. Then the user is taken back to the home page. In that case the software will keep the data obtained up to that exercise and, when the test is resumed, this will restart from the beginning of the previous interrupted exercise.

For each exercise there is a progression of difficulty, starting from the simplest version to the most difficult. Finally, every single test is provided with a pre-test phase which is useful to understand if the child has the prerequisites necessary for the task performance: for example, the forms recognition pre-test precedes a test that foresees the discrimination of forms. After the pre-test, an instruction and an example of the following test are shown and explained by the vocal assistant, to help the child focus and understand the following task.

The executive functions evaluated in the test phase and the related subtests are described below.

Attention.

- The Visual Attention test requires the user to select a target stimulus which occurs several times together with other distractors. As the test goes on, the number of stimuli increases and their size decreases.
- The Auditory Attention test requires the user to listen to some sounds, for example musical instruments, and press a button when he hears a specific one. The difficulty enhances when the number of items to listen to increases.

Working Memory.

- In the Digit Recall test (9-11 version) the user observes sequences of numbers that he must then remember and type on a final screen composed of digits from 1 to 9; in 6-8 version numbers are replaced by quantities of animals, from 1 to 5, but the procedure is the same. As the test goes on, the number of digits or quantities of each sequence increases.
- In Visuospatial Working Memory test the user must observe stars that light up in sequences and reproduce the observed sequence by selecting the stars in turn. The difficulty enhances as the number of stars that light up in each sequence increases.

Inhibition.

- Jump-No Jump test requires the user to make an animal jump when listening to the "Jump" sound and to make the animal stand still when listening to the "No Jump" sound, that is equal to the sound of "Jump" in the first part but different in the final part. As the test goes on, the time between one sound and another becomes smaller.
- In Matching test there is a picture that remains still on the left side of the screen; on the right-side other pictures alternate, some similar to the target one, that are distractors, and one equal to the target one. The user must select only the equal one. The difficulty increases when distractors are more similar to the target pictures.

Planning.

- The Labyrinth test [Fig. 2] is composed by classical labyrinths that the user must resolve, taking some animals to their rewards. Labyrinths are bigger as the test goes on.
- Food Composition test requires the user to create hamburgers, cakes and other food, but following some rules and having only a limited number of moves

available. The test becomes more difficult when the composition must be more sophisticated.

Cognitive Flexibility.

- The Card Sorting Test [Fig. 2] shows two pictures different in shape and color; then under the pictures, in turn, appear other pictures, identical in shape or color to those above. The user's task is to match the picture with one of the two pictures above, following the rules of "shape" or "color", provided by the vocal assistant.
- Trail Making test requires the user to link numbers from the smaller to the biggest. As the test goes on, digit increases and, instead of some numbers, appear numbers written in letters, that the user must consider linking them to other digits.

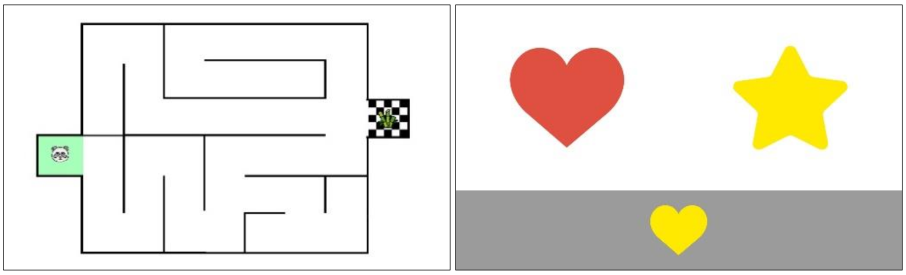

Fig. 2. On the left, an example of the Labyrinth test; on the right, an example of the Card Sorting Test

2.4 Training

The training area is under development: it provides specific training, with respect to each area presented in the assessment phase, through exercises and tasks that adapt to the child's starting level. At the beginning, the system highlights the areas of the test in which the child's performance is lacking and proposes specific exercises aimed at strengthening functions relative to that area. During the training there is a tutoring system that provides feedback and advice to the child while he is training. The tutor is presented to the child in the form of an animated character.

At a superficial level, the training interface has game design elements, in the perspective of gamification, to enhance the child motivation and attention. At a deep level, the software is provided with an intelligent tutoring system, so it is possible to collect data of the individual performance and, then, automatically provide the most useful strategy to be used to train a child; it is possible to calibrate the level of feedback and prompt that better fit with the child difficulty.

For example: if the child fails in the cancellation task, the system decreases the difficulty level reducing distractor items or lightening some target ones; if the child's performance is accurate, the following session difficulty level will become higher, increasing distractor items.

In order to measure the effectiveness of the training, after several training sessions, the automatic tutor will lead the user to perform the test phase again: thus, the achieved skills will be measured, and the scores will be compared with those of the first test administration.

2.5 Data recording

Evaluation and training phases involve the process of data recording and collection. A crucial aspect and one of the main purposes of the software is to point out accurate information about the performance, in terms of both quantity and quality. This application, as most software do, provides a controlled and structured environment that facilitates the data collection process.

For every single subtest we outlined a set of data to record including: performance accuracy in terms of score; errors and types of errors; trajectory on the screen; latency time between education and first interaction; total time; random execution.

Then, data collected are automatically available for users and organized through a cloud interface, that processes, stores and retrieves information from the software and, moreover, creates a simple and intuitive data display mode.

3 Standardization

Test standardization is currently in progress, as we are administering the subtests to a healthy population sample. Thus, we are creating standard scores that can be used to compare the data obtained from the test administration to a population sample with ADHD, so to determine the level of functioning of an individual at a specific age in comparison with standardization peers.

The sample consist of 300 children between 6 years and 11 years randomly selected from primary schools of Naples metropolitan area, divided between males and females.

After calculating the raw score of each area and subtest, the scores are converted into standard scores.

To understand if there are significant differences between the participants scores with respect to age and gender, statistical analyses will be carried out to verify their significance and to establish a subdivision into age groups for the comparison and attribution of scores of the population with ADHD.

Moreover, the reliability and validity of the test will be verified by re-testing children of the healthy sample and verifying the correlation of the subtests with other standardized tests that measure the same constructs.

4 Conclusions

The present work introduces the design of a software aimed at empowering executive functions of children with ADHD. Main purposes are, firstly, to validate the software and create a standardization sample for the test; secondly to collect accurate data; then to take advantage of that data to build an ITS.

Our purpose is to support children with a condition of ADHD and decrease the difficulties that derive from the malfunctioning of the executive processes: a possibility is to increasingly adapt the training to the real needs of the children and make it as much ecological as possible for the transfer of acquired skills to everyday life, above all to learning contexts as school.

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