Artificial Intelligence-powered cognitive training applications for children with attention deficit hyperactivity disorder: a brief review[1*]

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Abstract. Attention deficit hyperactivity disorder (ADHD) is a complex neurodevelopmental disorder whose symptoms are related to poor learning outcomes, low executive functioning and parental stress. e-Health applications aimed at enhancing cognitive processes and executive functions for ADHD are emerging technologies.

The present work reviews Artificial Intelligence (AI)-powered applications developed for children with ADHD by highlighting their impact and scientific support. We considered both mobile and desktop applications. The first were selected from Google Play and Apple Store, whilst PCs applications were selected from online magazines devoted to ADHD. Related scientific studies were then identified through Google Scholar, PubMed, and APA PsycNET databases.

Research results reveal a critical lack of scientific support for mobile applications, only 2 are supported; otherwise, PCs applications are supported by multiple studies, although with small samples. Some applications are provided with intelligent tutoring and self-paced learning activities, but more scientific studies are needed to test their effectiveness for supporting children with ADHD.

In conclusion, these software are promising, however, there is still a paucity of scientific support, a crucial aspect when a tool is intended to improve specific difficulties of children with complex neurodevelopmental disorders.

Keywords: ADHD, children, software, training, applications, AI, intelligent tutoring

1 Introduction

Attention deficit hyperactivity disorder (ADHD) is a complex neurodevelopmental disorder [1]. The prevalence of ADHD ranges between 3% and 5% among school-aged children worldwide [2] [3] [4].

Cognitive neuropsychological researches [5] have very often found that children with ADHD present attention problems especially in tasks requiring application of

controlled processes. Particularly, children with a condition of ADHD experience difficulties in carrying out prolonged tasks in which vigilance is requested over time, in selecting the necessary information for performing a task or in orienting the attention toward a specific direction in space. Some children with ADHD seem to respond to the stimuli they receive from the context inappropriately, and act without thinking. Impulsive children behavior is characterized by poorly regulated responses: children have difficulty in inhibiting a predominant response, in controlling interferences (i.e. external stimuli competing with the main behavioral pattern required). Hyperactive children show an excess of irrelevant movements with respect to the task and situation [6].

ADHD has been associated with a malfunctioning of cognitive and executive functions [5][7] as inhibition, verbal and visual working memory, cognitive flexibility, planning. Executive functions are high level abilities with which individuals manage thoughts and actions, guide their behavior across time more effectively, considering the long-term consequences of their actions.

Besides ADHD key symptoms, there are several long-term difficulties associated to deficits, like learning problems and low levels of self-esteem. Children with ADHD have often social difficulties: they tend to be more polemic, aggressive and unstable, which can lead to rejection and social isolation [8]. This in turn leads to a low quality of life for children and families, who experience high levels of stress. Moreover, there is a substantial comorbidity of ADHD with conduct disorder, oppositional defiant disorder, mood disorders, anxiety disorders, learning disabilities, and other disorders [9].

As claimed by main guidelines, each therapeutic intervention for children with ADHD must be carefully customized, preceded by a global clinical evaluation. According to data from the scientific literature, ADHD is currently being treated with multimodal methods [10]. Pharmacological treatments with psychostimulants are the most common, but also behavioral cognitive therapies focusing on enhancing children's self-control, problem-solving skills and adaptation are widely applied. Finally, social interventions support children in relation with peers; treatments often involve teacher and parent training. Medication treatment is the main administered one and it is considered an effective and powerful resource to deal with a condition of ADHD; indeed, it is effective in the short/medium-term period, but it has potential limitations such as the risk of side effects. The combination of treatments offers some advantages compared to the exclusively pharmacological treatment as it allows to use smaller doses of medicine.

The widespread diffusion of new technologies worldwide, has ignited the development of e-Health platforms and software for cognitive and behavior disabilities that made possible the transformation of mental health interventions, occurred in different contexts [11]. Computer-based training uses software that have been designed to help children improving cognitive and executive functioning [12]; moreover, gamified training of cognitive functions has one more element, which is the aspect of the game that motivates children and empowers the learning process [13]. Apps for mobile devices could offer flexible e-Health platforms functional to the management of chil-

dren's behavior, creating network of caregivers useful for planning and scheduling interventions. Moreover, software can record more accurate, direct and reliable data, that keep track of training progress and of the acquisition of new skills.

Artificial intelligence in the last decades has attracted attention for its ability to turn data into valuable knowledge. We can speak to our electronic devices because AI algorithms recognize and process natural language to satisfy our requests. Many applications make use of AI for different purposes with the objective to improve their AI free counterparts. Indeed, the potential impact of AI in eHealth applications for ADHD could be very important. AI, in fact, could ensure greater effectiveness of the intervention, to guarantee a fully customization based on the user's performance and specific characteristics. An AI-powered system could collect data on user's performance and could use those data to calibrate subsequent levels, for example to adjust training difficulty levels [14] [15] [16].

1.1 Purpose of the review

The present review aims to examine the validity and impact of AI-powered applications for cognitive functions training in supporting the management of cognitive difficulties of children and young people with ADHD. We considered both mobile and desktop applications.

This study aims to highlight the intrinsic characteristics of software supported by scientific studies: the goal is to point out software powered with an intelligent tutoring system and to examine whether they are based on a simple or a complex functioning. Finally, our purpose is to highlight whether an internal reporting system and data processing is integrated in those applications: automatic data reports could be useful to a parent, caregiver or teacher to understand their children's progresses.

Parents of children with ADHD could use software and applications with the hope of giving their children useful tools for clinical and rehabilitative purposes; often the use of these tools extends also to institutional settings such as schools or other learning centers. Therefore, we consider it necessary to conduct this review to help readers to distinguish entertainment products from those which have been developed on solid scientific and technical basis.

2 Methods

A survey of mobile apps (developed for smartphone and tablet devices) was conducted in the Android Google Play and the Apple iTunes Store in Italy, other software (designed for computer desktop) were selected in online magazines dedicated to ADHD [17]. Applications supported by scientific studies were identified using databases such as Google Scholar, PubMed and APA PsycNET. The survey was carried out in January 2019.

The inclusion criteria for software research were: apps or software aimed at ADHD, apps or software targeted at children or young people with ADHD between 3 and 18 years old, apps or software aimed at caregivers of children or young people with

ADHD. The exclusion criteria for software research were: apps or software that do not state they are aimed at ADHD, apps or software not targeted at children or young people with ADHD or their caregivers. The inclusion criteria for scientific studies on apps and software were: scientific studies carried out on the retrieved applications and software involving children with ADHD.

3 Results

Within the repositories listed in the previous section (Google Play, Apple Store and ADHD magazines) we found 16 apps for mobile devices and 7 software desktop applications for children and young people with ADHD. Of the 16 apps found, only 2 were supported by scientific studies [18] [19] [20], of which one is a single case study, that is not enough to validate the effectiveness of the app. Among the 7 desktop applications found, 4 are supported by scientific studies [21-27]. Main features of software (summarized in Table 1) are described below.

Table 1. Summary of software

Mobile Apps	TALI Train™	Selective attention, control, inhibition and focus training
Desktop Apps	Braingame Brian	Visuospatial working memory, inhibition, and cognitive flexibility training
	Play Attention	Executive functions (working memory, spatial memory, short-term memory, planning, attention, and more) training
	ATENTIVmynd™ Games	Training of cognitive functions: focused and sustained attention, cognitive and behavioral inhibition, divided attention, interference control, self-regulation and more.
	Cogmed Working Memory Training®	Working memory and executive functions training

3.1 Mobile Apps

TALI Train™ software has an AI system that adapt to each child's abilities; the task difficulty is automatically adjusted. An interactive guide provides visual and verbal instructions as well as support and encouragement. The application presents game scenarios and activities, which include animals, for example fish to locate among a series

of distractors, pirate ships and others. An in-built reward system is used to increase children's motivation to complete the program. The TALI Train™ software has a tracking and analysis progress system: it generates reports based on the child's performance, which give clinicians, teachers and parents an insight into the child's progress. Data-analysis software underpinning the game measures achievement, accuracy and reaction time.

The efficacy of TALI Train™ was investigated in children with intellectual and developmental disabilities and attention difficulties in two double-blind controlled study [19][20]. 76 children aged 4–11 years were assigned, in both studies, to TALI Train™ training condition or a control condition. Results of the first study indicates that there was a modest improvement in selective attention for children in the TALI Train™ condition. However, the training did not have any specific effect on sustained attention, attentional control or parent/teacher-rated behavioral attention difficulties. In the second study no training effects resulted at post-training but children in the training group showed greater improvements in numeracy skills at the 3-month follow-up.

The main limitation of this studies is the small sample of children with intellectual and developmental disabilities that are not differentiated according to the diagnosis, so it is difficult to understand if there is an influence of individual characteristics on training outcomes. Despite this, compliance of children with the training program was high (90%) and all children finished every assessment session, an important aspect since the children all had cognitive and attention deficits.

3.2 Desktop Apps

Braingame Brian is a serious game that adjusts the difficulty level of the tasks according to the user's performance: for example, in the working memory task some rectangles light up in a random sequence and the child must reproduce the sequence; the sequence length is automatically adapted to the child's level of performance, so, if he performs few correct responses, the sequence length is shortened and vice versa.

Gamification is integrated in the software in order to enhance motivation: inside the game environment there are seven different worlds and a main character, Brian. He helps all the other characters to solve their problems. Brian is provided with an internal data reporting system able to collect users' data. Trainers receives online feedback in terms of learning curves for the three different training tasks.

Children between 8 and 12 years old with a diagnosis of ADHD were recruited to participate to a study involving Braingame Brian training [21] [22]. 21 children were randomized to the treatment condition and 22 to the wait-list control condition. The results showed that children in the treatment condition significantly reduced ADHD behaviors and improved executive functions compared with children in the wait-list condition. However, significant improvement were found in inhibition subscale of the outcomes test, but not in the working memory and set-shifting subscales. Limitations of this study are the small sample size and the fact that the children training outcomes were evaluated only through parents' reports: parent-rated reports are not very reliable

measures of the improvement of children's executive functions, so it would be necessary to implement a specific neuropsychological evaluation for each separate cognitive function.

Play Attention is a training software with a specific neurofeedback system that detects 2 frequency ranges, 1 in the low-frequency theta brainwave range (4–8 Hz) and another in the high-frequency beta brainwave range (12–15 Hz) by an EEG. Through practice, participants learn to manipulate the figures displayed on the screen, resulting in suppression of theta and an increase in beta activity. As the theta/beta ratio changes, an algorithm helps users improving attention on the 6 different exercises. The computer interface gives immediate auditory and visual feedback to the children about the degree to which they are successful in paying attention. The game, for example, involves flying an airplane: is the child concentrates, the airplane will go up, and if not, the plane will go down. Play Attention is provided with an internal progress reporting system: a baseline is set at the beginning of each session, and as the children progress they reach higher (more challenging) levels.

Two studies evaluate the efficacy of Play Attention software [23] [24]. The most recent study [24] randomly assigned 104 children with ADHD to Play Attention training (34), simple cognitive training (34), or control conditions (36) in school setting. Results showed that children in the Play Attention condition improved the inattention behavior and the executive functioning, also over time, instead children in the CT condition didn't show significant pre-post differences. Moreover, results showed that participants receiving stimulant medication in both control and CT conditions increased their dosage (measured at preintervention and/or postintervention), instead participant in the Play Attention condition increased their dosage minimally.

Among limitations of the study there is the small sample of participants; moreover, all outcome measures were completed by parents, teachers, and blinded classroom observers at pre- and postintervention, so there isn't a direct measure of participant cognitive abilities.

ATENTIVmynd™ Games is a software that uses a feed forward modeling system that calculates the user's attention states. Gamification is integrated into the software because there are several games with which the child can train, for example Cogoland, a game with an avatar that the child can guide to achieve the goals of different levels.

ATENTIVmynd™ Games is provided by a machine learning algorithm that pick up useful information about attentional activities from the recorded frontal EEG signals and then send the feedback using the computerized three-dimensional (3D) graphic game presented on the screen. The algorithm transforms the child's state of attention into a value between 0 and 100%, allowing him to calibrate his attention to control the speed of the game. For example, in one game, each participant must complete a task controlling an avatar, making the avatar run around an island in the shortest time possible. The avatar run faster if participants are more attentive.

The software contains a Mission Performance Reports (MPRs), a personalized data analysis, that allow parents to be involved and informed of their child's improvements of attention, inhibition and cognitive skills, through visually intuitive, graphic representations.

The most recent study on ATENTIVmynd™ Games [26] examined the topological alterations of large-scale brain functional networks induced by software on ADHD children using resting-state functional magnetic resonance imaging method. After training the intervention group (N=18) showed improvements in attention abilities, compared to the non-intervention group (N=11), but also differential brain network reorganizations, as increased functional connectivity within the salience/ventral attention network (SVN) and between task-positive networks (including the SVN, dorsal attention, somatomotor, and executive control network) and subcortical regions. Limitation of the study is the small sample of participants.

In **Cogmed Working Memory Training®** software contains multiple exercises, such as "Animals", a game in which some animals on a panoramic wheel are highlighted in sequences; the children must remember the order and repeat it. For each correct response, the child gains a starfish. All starfish are collected during the training and stimulate children motivation.

Moreover, the difficulty level of every exercise of the training is adjusted in real time, based on the user's performance. There is a highly fine-tuned calibration so that every user always trains at the very edge of cognitive capacity. Cogmed Working Memory Training® (CMWT) provides an online data reporting system that both users and the Cogmed Coach can review and monitor each day of training. After the whole training, the Coach summarizes the results together with the user and provides feedback data from rating scales and from the Cogmed Coaching Center.

Children between the ages of 7–11 years with a diagnosis of ADHD were included in a study [27] with the aim of evaluate the efficacy of CWMT (N=44) compared to a well-controlled placebo version of CWMT (N=41). No significant improvements were found in teacher rated ADHD inattention symptoms and no significant differences were found between training group and placebo group on inattention, hyperactivity/impulsivity symptoms based on parent's reports. Working memory direct measures showed greater improvements of nonverbal and verbal storage in the CWMT group, but no significant differences were found on measures of nonverbal or verbal storage plus processing/manipulation between treatment conditions.

Despite the absence of a wait-list control condition, strong point of this study are not only direct and objective assessments of working memory, but also of attention, activity level, and impulse control, that showed no significant differences of inattention, impulsivity or activity level between treatment conditions. Within this study also academic achievement were evaluated, as word reading, sentence completion, math computation and spelling, but no significant differences were found between treatment conditions at posttreatment.

4 Discussion

The motivational aspect of training is important for ADHD patients as much as for the healthy population. The first aspect that we want to emphasize is that of the gamification: all the software have a gamification system that increases children's motivation, moreover they provide rewards for the attainment of objectives, such as keeping

attention on the task. It is necessary for a cognitive functions treatment to be characterized by motivating aspects that involve children's attention, so that they remain on the task and enhance their skills.

The listed applications make use, in different extent, of Artificial Intelligence, manly used in managing the difficulty of the task. Especially, most of the tools allow to adjust the difficulty level of tasks based on user's performance, which give the training the opportunity of being customized according to the user's needs. However, AI is not fully exploited in our opinion, applications could implement and automatic diagnostic and assessment tool [28] or gather data to model ADHD behaviors by using neural networks [29] [30] [31] or a form of digital to real world robotic platform [32]. Moreover, an AI system could suggest the best type of stimuli and prompting, through an automatic tutoring process, that could stimulate users to improve their performances. However, the method with which this process takes place is not clearly described by the authors.

Moreover, AI is deeply used in neurofeedback software. Neurofeedback has been used to improve physiological self-regulation skills in children with ADHD and it showed significant decreases of the ADHD core symptoms [33] [34]. Neurofeedback provide auditory and visual feedback to the users about their performances in specific tasks, so it uses real-time physiological sensing. These studies highlight the neurofeedback potential combined with the use of computer-based training and videogames: neurofeedback allows to analyze sophisticated data of attention's level from electrodes, calibrate and send to users the appropriate feedback based on the data collected. Feedback have a crucial role in maximizing the engagement level of ADHD children during training.

Every application is provided by an internal or online data reporting system which is functional for updating users and caregivers on performance training progress. Although the type of system used is not always specified, this is certainly a software strength. However, most of studies utilize indirect measures of training outcomes in ADHD main symptoms, as parents or teachers report; it would be useful to integrate direct and objective measures of children's cognitive and executive abilities pre and post-interventions abilities to better evaluate the efficacy of interventions and training.

5 Conclusion

This brief review reveals a promising efficacy of the software aimed at improving specific difficulties of children with a condition of ADHD, however we highlight a critical lack of scientific support in the case of applications for mobile devices; desktop application on the other hand are scientifically better supported. However, considering the widespread popularity and flexibility of mobile devices this lack of scientific support reveals a scarce scientific attention to ADHD in this specific context. Clearly, apps need further scientific support to give users with ADHD effective tools able to improve some aspects of their daily life.

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