# ASTRAS: a software for the assessment and training of executive functions in children

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**Abstract.**

Executive functions are a set of cognitive processes (working memory, cognitive flexibility, attention, inhibition and planning), which are crucial for a goal-oriented behavior.

A deficit of the executive functions has been reported in several neurodevelopmental disorders, chiefly among them attention deficit/hyperactivity disorder (ADHD) and learning specific disorder (LSD). In these clinical conditions, the impairment of the executive functioning has a significant impact on the therapy and its gains. Hence, the assessment and training of these cognitive processes should always be a matter of special attention by the therapist.

Consistently with this, we developed "ASTRAS", an application for the assessment and training of the executive functions in children with neurodevelopmental disorders.

ASTRAS has two main features: 1) two types of use (therapists and parents), which offer the opportunity to start (therapists)/run (parents) the assessment/training session from remote. In other words, ASTRAS can be used as a tool for the telerehabilitation (or e-rehabilitation); 2) gamification, which offers the opportunity to work on both specific executive skills and motivation.

In conclusion, ASTRAS will improve executive functions in children enhancing their engagement/motivation about the therapy.

**Keywords:** Executive Functions, Telerehabilitation, Computer-Based rehabilitation.

# 1 Introduction

Executive functions (EFs) is an umbrella term which encompasses a set of interrelated cognitive processes, such as planning, working memory, inhibition, cognitive flexibility and attention [1, 2]. These processes are associated with problem-solving, decision making and goal-oriented behavior, which in turn allow the individual to cope with novel situations and complex or conflictual information [3]. In other words, EFs underlie individuals' adaptive behaviors to the changing environment.

Childhood is a highly sensitive period regarding the development of EFs [4] and since these higher order functions play a fundamental role in cognitive development, there is no doubt that deficits of executive functioning may be reported in several neurodevelopmental disorders such as attention deficit/hyperactivity disorder (ADHD[5, 6], learning specific disorder (LSD [5, 7]), autism spectrum disorder (ASD; [8, 9]), in preterm children [10] and in several genetic syndromes (Prader-Willis and phenylketonuria).

Deficits of executive functioning in these populations affect the severity of the disorders. For example, in children with ADHD a dysexecutive syndrome has been associated to learning impairment, problems with academic achievement as well as maladaptive and/or aggressive behaviors[11]. In their study, Schreiber et al.[12] reported that children with ADHD performed worse on the working memory task as compared with the controls. In this group, the score in a working memory task predicted learning problems. Other studies confirmed these results [13, 14].

Watson et al. (2016) discussed the impact of EF in learning disorder (LD). The authors stated that "students with LD often evidence significant problems in EFs which includes working memory operations (updating), inhibitions of impulses (inhibiting), and mental set or task shifting (shifting)". These problems "are usually manifested by ineffective ways to plan, monitor their own learning, and detect and correct their errors."

Considering the importance of EFs in children with both typical and atypical development the assessment and the training of these particular cognitive processes has received considerable attention [4, 15]. Notably, in children with neurodevelopmental disorders, deficits of executive functions -and their impact on the severity of syndrome- should always be taken into account and interventions fostering EF in these children should be provided along with the traditional therapy.

Among several tools for the assessment (see Poletti and Montanari, 2014[16] for a review) and training of executive functions [4, 17] alternative methods - widely used for other cognitive processes [18–21]- are receiving a growing interest.

A good example are the computer-based tools (i.e. software, apps, videogames and serious games). These tools have several advantages. For example, assessment or training tasks can be converted into games (i.e. gamification). Gamification, that is the application of typical elements of game playing (e.g. point scoring, competition with others, rules of play) to other areas of activity [22, 23] in order to encourage children's engagement and motivation. Furthermore, computer games allow to progressively increase -or decrease- the load of a specific executive domain relying on individual's

performance. Thus, they avoid frustration and therapy drop-out. The efficacy of computerized training has been reported in literature. For example, Klingberg et al.[24] conducted a trial to investigate the effect a computer-based training of working memory in a sample of children with ADHD. In this study, working memory significantly improves after the training. The effects were observed even on untrained tasks (i.e. response inhibition, and complex reasoning) and were observed at the follow-up (i.e. three months later). Similar results with computerized training of executive functions have been reported in literature by Thorell et al. [25], Holmes et al. [26]and Karbach & Kray[27].

Although an increasing number of technological platforms have been released (e.g. CogMed; CogniFit; Neurnation; ACTIVATE), this research field is still young and a lot of work is needed. For example, to our knowledge, to date no one has developed a computer-based tool for the assessment of executive functions in children with neurodevelopmental disorder or at least a software in which the assessment part communicates with the training part. Additionally, computer-based tools should allow therapist to start the assessment/training session from remote offering the opportunity to provide a telerehabilitation or e-rehabilitation service.

Here, we described ASTRAS, a software developed in our lab, aiming at assessing and training EFs in children with neurodevelopmental disorders.

## 2 ASTRAS

ASTRAS[1] is a cross-platform software (iOS, Windows, macOS and Android) for the assessment and training of EFs. The software is designed for children, with neurodevelopmental disorders (e.g. ADHD, LSD, ASD), in which these particular cognitive domains are impaired (see above). The software uses some gamification principles. That is, assessment and training tasks share the characteristics of game elements such as: 1) design: the assets of each task (i.e., scenario and characters) are cartoon-like. Furthermore, training's tasks have a common theme, the space; 2) mechanics: tasks have been designed as challenges in which children can also compete with others. Additionally, children receive a feedback about their performance (only in the practice session of the assessment tasks and in each training tasks, see below) and a reward each time they successfully accomplish a training task; 3) components: assessment and training tasks have been designed with different levels of difficulty, thus increasing the load of the specific executive domain.

Bind together, these game features aim to improve children engagement, motivation as well as learning.

[1] For a demo version of the software contact the authors.

### 2.1 General structure

ASTRAS is designed for children from six to eleven. We targeted this range because even though rudiments of EFs emerge before early childhood [28], and a rapid improvement in EFs tasks have been observed in preschoolers [29], these particular cognitive processes are more likely to mature in scholar period and adolescence [30, 31].

There are two types of use/access in ASTRAS. Each type of use/access includes different features as reported below:

- Therapists/Tutors: this type of use/access is designed for those professionals (psychologist, neuropsychiatrist, speech therapist, etc.) who work with children with neurodevelopmental disorders. This type of use allows to: 1) register a new child, modify his/her data or delete his/her profile; 2) open an individual or group assessment/training session; 3) assign exercises to a singular child or a group of children; 4) visualize children's scores.
- Parents: this type of use/access is designed for children. This type of use allows to visualize and run the assessment tasks or the training exercises assigned by the therapist.

The two types of use/access and their features foster the feasibility of the e-rehabilitation. In fact, therapists can use ASTRAS software in clinical context (vis-à-vis), but also from remote.

ASTRAS also includes two different sessions, namely an assessment and training. Both sessions take into account five main executive domains, commonly reported in the literature [32, 33], that is: selective attention, inhibition, cognitive flexibility, planning and working memory. Specifically, we referred to Myake et al.[34] as theoretical framework. The model posits that there are three core EFs:

1) inhibition: reflects the ability to control own behavior, thoughts, and/or emotions to override a strong internal predisposition. Inhibition can be divided in behavioral inhibition (i.e. the suppression of a prepotent motor reaction) and cognitive inhibition (i.e. the suppression of a prepotent mental representation);
2) working memory (WM): reflects the ability to hold verbal (verbal WM) or spatial (spatial WM) information in mind and mentally working with/on it. Additionally, WM includes the updating, that is the incorporation of new information into the old ones;
3) cognitive flexibility: refers to the ability to switch between thinking about two different concepts or to think about multiple concepts simultaneously.

From these core EFs, is built the planning. Planning is a higher order EF and reflects the ability to set goals, develop action plans to achieve those goals, and to choose the most appropriate actions based on the anticipation of consequences. Additionally, in this model, selective attention, namely the ability to selectively focusing on a target stimulus and suppressing attention to other stimuli or external lure, has been conceived playing a crucial role in the correct development of EFs.

Below we provide a more accurate description of the assessment and training sessions (i.e. their general structure and their respective tasks).

## 2.2 Assessment

Assessment includes ten tasks, two for each executive domain (selective attention, working memory, inhibition, cognitive flexibility and planning, see figure 1 for the interface).

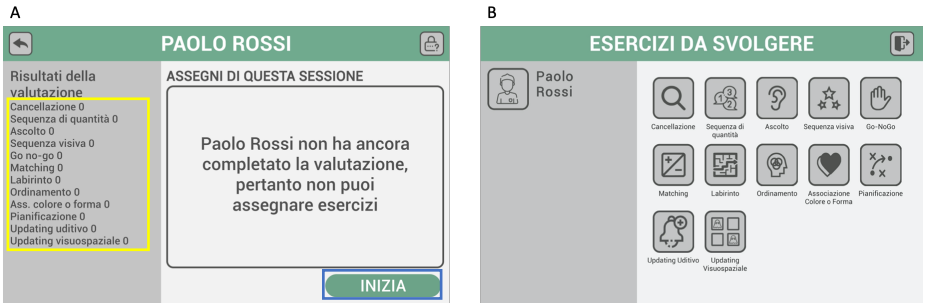


**Fig. 1.** The assessment interfaces for therapists (A) and parents/children (B) are shown. Therapist interface reports the list of tasks and their respective scores (yellow box) and the button to start the assessment session (blue box). Parents interface reports the icon of each assessment task.

Additionally, other two tasks have been developed to assess the updating of working memory. Each task consists of trials, which progressively increase in difficulty. Tasks are preceded by four steps (Figure 2):

1) starting: a traffic light which informs children that the task is going to start;
2) pre-test session: this step taps whether children have developed those cognitive processes mandatory to run the test (e.g. in the cancellation task, the pre-test verifies whether children are able to discriminate a target picture). If this session is failed twice the task ends;
3) simulations: in this step a video shows an example of trial;
4) practice session: in this step children are provided a practice trial. The aim of this step is twofold: a) to allow the participant to practice with the task; b) ensure that children have clearly understood the instructions. If the patients fail this session once, the simulation will be provided again. If the patients fail twice, the task ends.

The score in each task range from 0 to 100 in terms of accuracy. Further data such as reaction times, omissions and commissions errors (e.g. selective attention tasks), number of moves (e.g. in the maze task) are stored into ASTRAS's database. These additional data make ASTRAS useful for research purposes or to address other clinical issues.

Below a small description of the tasks for each cognitive domain has been provided.

- Cancellation: it assesses the visual selective attention. In this task, children are shown a clutter of items, and asked to tap with their finger the target item (e.g. a star), ignoring the other stimuli.
- Listening: it assesses the auditory selective attention. In this task, children are provided a sequence of animal sounds. They have to tap a paw on the center of the screen when they hear a target sound (e.g. a frog).
- Sequence of quantity: it assesses the working memory. In this task, a sequence of numbers appears on the screen. Children have to repeat the sequence either forward or backward.
- Visual sequence: it assesses the visuo-spatial working memory. In this task, a sequence of flashing stars is visualized on the screen. The participant has to reproduce the sequence either forward or backward.
- Auditory updating: it assesses the auditory updating of working memory. In this task, children listen to the tones in sequence. After each tone is heard children decide whether the new tone is the same from 1 (1-Back) or 2 trials (2-Back) before.
- Visual updating: it assesses the visuo-spatial updating of working memory. In this task, children have to decide whether the position of a ghost is the same of 1 (1-Back) or 2 trials (2-Back) before.
- Go-No Go: it assesses the motor inhibition. In this task, children have to move a penguin only when he/she listen to a GO sound.
- Matching: it assesses the cognitive inhibition. In this task, children have to identify, from a subsequent set of stimuli, the one that "matches" the sample.
- Color-shape association: it assesses the cognitive flexibility. In this task, children have to choose, from two stimuli displayed on the top of the screen, the one that has the same target criterion of the sample (shape or color). The target criterion is provided by the software.
- Trail: it assesses the cognitive flexibility. In this task, children have to tap in ascending order a clutter of numbers and letters.
- Maze: it assesses the planning. In this task, children must trace through a maze without crossing the maze lines.
- Planning: it assesses planning. In this task, children have to reproduce a picture (e.g. a cake) in a given number of steps.

### 2.3 Training

Training includes ten tasks/games, two for each executive domain. Here, the therapist chooses: 1) the executive domain to train; 2) the specific task/game for that executive domain; 3) the number of exercises; 4) the difficulty (1 to 4); 5) the prompt (i.e. the visual or auditory support to help children in accomplishing the task). Figure 2 reports the training interface.

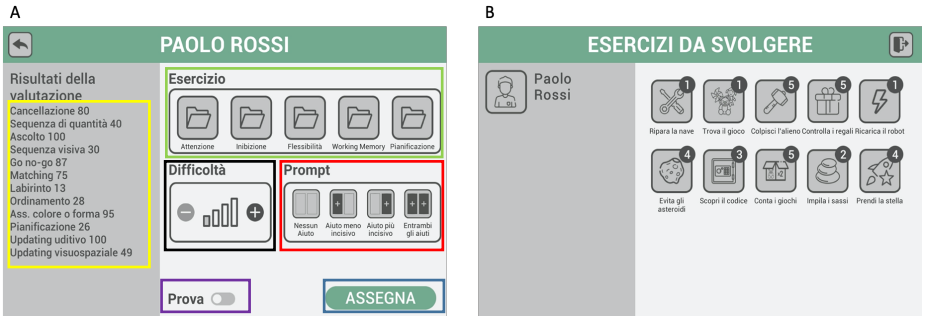


**Fig. 2.** The training interfaces for therapists (A) and parents/children (B) are shown. Therapist interface reports the list of assessment tasks and their respective scores (yellow box), the interface to choose exercises (green box), the difficulty (black box), the prompt (red box), the practice (purple box) and the button to start the training session (blue box). Parents interface reports the icon of each training task and the number of exercises for each task.

Below a small description of the tasks for each cognitive domain has been provided.

- Fix the spaceship: it trains the visual selective attention. In this task, children have to drag a target object (e.g. pliers) into a toolbox, ignoring the other stimuli.
- Find the toy: it trains the visual selective attention. In this task, children have to choose the correct color of a target stimulus (e.g. a teddy bear) -ignoring the non-target stimuli- by pressing the correct button.
- Unlock the code: it trains the working memory. In this task, children have to memorize the code of letters and numbers and type it on a safe's keyboard by pressing first the numbers and then the letters in ascending order.
- Count the toys: it trains the updating of working memory. In this task, the trial is visualized as a sequence of dolls and teddy bears falling into two separate boxes. When the sequence ends, children have to report the number of either dolls or bears in one of the two boxes (target box).
- "Whac-an-alien": it trains the motor inhibition. In this task, aliens pop up from some holes disposed on the screen. Children have to hit the red alien and not the green one. Red aliens are more likely to occur.
- "Check the toys": it trains the motor inhibition. In this task, children have to decide whether a toy is broken or it is different from the target by pressing the relative buttons. No button needs to be pressed if the target toy is intact.
- "Charge the robot": it trains the cognitive flexibility. In this task, children have to choose the correct battery: if the robot dreams an empty geometrical figure the correct battery is the one with the same figure; if the robot dreams a colored geometrical figure the correct battery is the one with the same color.
- "Dodge the asteroids": it trains the cognitive flexibility. In this task, children have to dodge the asteroids. The correct direction is given by the color of an arrow displayed on the screen: The direction is congruent if the arrow is green; incongruent if the arrow is red.

- "Pile the stones": it trains the planning. In this task, children have to pile a set of stones in the correct order.
- "Reach the star": it trains the planning. In this task, children have to decide the sequence of rightward and/or leftward movements in order to reach the goal.

## 3 Conclusion

In conclusion, our software can be thought as a platform hosting several tasks/games for the assessment and training of executive functions in children with neurodevelopmental disorders. ASTRAS offers the advantage to provide training tasks from remote and control patients' score ongoing and to change: 1) the type of executive domain to train; 2) the difficulty level; 3) the prompt. In other words, the software might be a useful tool for telerehabilitation. Furthermore, gamification has been applied in our software in order to increase children's engagement and make the experience of the therapy more enjoyable as well as avoid drop-out.

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