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Stimulation of executive functions with embedded preliteracy skills in high ability preschoolers: An educational software

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Abstract

The predictive role of the three core executive function components-working memory, inhibition and cognitive flexibility-on later academic achievement has long been examined and confirmed. Additionally, research evidence indicates that executive functions rapidly advance in the preschool years and they interrelate with preliteracy skills. High ability preschoolers manifest a great variability on neuropsychological measures and phonological awareness within their population, despite their intelligence quotient scores in the above average range. This paper presents the Gogni-PreLit (Cognition and Preliterature) application, an educational training software which stimulates core executive functions with embedded preliteracy activities. It was developed to meet the needs of high ability preschoolers whose education calls for enrichment, with a focus on phonological awareness. The user's interface, the application flow, with details for each step, the type of data stored in a central database after each training session and a game example are described.

Key words: *Executive functions, preliteracy, high ability preschoolers, Cogni-PreLit*

Introduction

Executive functions (Efs) refer to cognitive processes that are necessary for goal-oriented behavior. Although the concept of Efs has rapidly grown into an umbrella term for many automatic and conscious learning processes, there is a general consensus that there are three core Efs that underlie these processes (Diamond, 2013; Van de Sande, Segers, & Verhoeven, 2015). Those core functions are inhibition, working memory (WM), and cognitive flexibility, mainly because they are clearly outlined and therefore their operation can be defined with relative accuracy.

Inhibition refers to the ability to deliberately inhibit dominant, automatic responses. Shifting involves moving backwards and forwards between multiple tasks, operations, or mental sets. WM requires monitoring and coding of incoming information and appropriately revising the items held in short-term memory by replacing no-longer-relevant information with new, more relevant information (Miyake et al., 2000).

Many researchers have examined the predictive role of the three core Ef components -WM, inhibition and cognitive flexibility on later academic achievement in typically developing children, due to the rapid advances in Efs that take place during preschool years (Garon et al., 2008; Zelazo et al., 2003). In particular, associations between all EF components and language skills development in preschool children have been documented in recent research (Veraksa et al., 2018).

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The interrelation between executive functions and phonological awareness

The advances in Efs in the preschool years contribute to a monitored, self-controlled, and abstract learning (Munakata et al., 2012). Such learning involves exactly the processes that are needed to acquire phonological awareness (PA), which has been found to predict reading acquisition (Cartwright, 2012).

PA skills require children to reflect consciously on the phonological segments of spoken words and to manipulate them in a systematic way. Among these skills, which are performed in different types of tasks, rhyming (judging whether two words rhyme), matching rhyme and alliteration, syllable blending and splitting, full phoneme segmentation and manipulation are hierarchically included (Anthony & Francis, 2005). Furthermore, for the emergence of phonological awareness to occur, children must be able to switch their attention from the meaning of a word to its structural features (Walcott et al., 2010).

Efs contribute to PA in manipulating the spoken representations in mind and by suppressing attention to irrelevant phonological codes (Foy & Mann, 2013). Most important though, is the fact that recent research provides data to support significant associations between all EF components and oral language skills development in preschool children (Veraksa et al., 2018). For example, some studies have identified inhibition as closely linked to performance on pre-reading tasks (Miller et al., 2013), involved in the process of acquiring automaticity in letter identification (Blair & Razza, 2007) and early orthographic knowledge skills (Shaul & Schwartz, 2014). Convincing data supports the importance of WM to PA and reading letters, words and nonwords, with inhibition related to the segmentation task (Preßler et al., 2014). As PA develops, the performance level of WM also increases and vice versa. The higher the levels of PA and WM, the more advanced the literacy phase of a child will be. This means that these are directly proportional measures (Cardoso et al., 2013).

Indeed, recent research has also found evidence of bidirectionality between Efs and young children's language skills, with language being a stronger predictor of Efs development than vice versa (Slot, & von Suchodoletz, 2018).

Executive functions and phonological awareness in high ability preschool children

High ability children perform—or have the capability to perform—at higher levels compared to others of the same age, experience, and environment in one or more domains (intellectual, academic, creativity, arts etc.). Modifications to their educational experiences are required, so as to learn and realize their potential (NAGC, 2019).

Research has linked high abilities to superior executive functions development (Fiske & Holmboe, 2019; Howard et al., 2013), with evidence of an early and efficient use of executive functions by high ability children. Compared to their typically developing peers, these children have higher levels of cognitive flexibility, inhibitory control, working memory and planning which promote a superior development of fluid intelligence (Barbey, 2018) and superior effectiveness in tasks that require working memory, flexibility, and automation of cognitive control (Rocha et al., 2020). The association between verbal and nonverbal intelligence with Efs in preschool children has been documented in recent research, with WM showing the strongest relation (Rahbari, & Vaillancourt, 2015) and Efs predicting advanced learning and high abilities in preschool years (Howard, & Vasseleu, 2020).

Nonetheless, although high ability children appear to have higher WM capacity than typically developing children, as well as more effective executive attention (Kornmann et al.,

2015), manifest a great variability on several benchmarking cognitive, academic and neuropsychological measures within their population. This manifestation is observable, despite their intelligence quotient scores in the above average range (Hernández Finch et al., 2014). With regard to preliteracy skills, the majority of high ability children solve the code of reading and writing at the ages of four to five by themselves. However, there are also high ability children who are unable to learn how to read during periods of preschool and primary school first grade (Bayraktar, 2016).

Consequently, considering the great variability high ability preschoolers demonstrate in the domains of Efs and language, enrichment programs that empower Efs and preliteracy skills, implemented in the classroom, may meet their needs.

EFs computer-assisted stimulation

The past decade extremely positive beliefs have emerged regarding the use of computer-assisted training of Efs. There is a plethora of software, online and mobile applications, which address children's population and are supported by conducted scientific research (Jaeggi et al., 2017; Rachanioti et al., 2018). Nevertheless, a limited number of studies have investigated the effect of Efs training on typically developing preschool children (Rueda et al., 2012; Thorell et al., 2009; Bergman Nutley et al., 2011), while Cardoso et al. (2018) underline the importance of such programs for Efs stimulation. Early preventive cognitive training programs will provide sufficient stimulation, such that the neurocognitive skill is experienced and improved (Dias & Seabra, 2015). Additionally, educational software programs are increasingly becoming part of the high ability students' learning environments. By that way, high ability learners receive individualized instructions matching with their needs, interests, and abilities. Importantly, they immerse themselves in completing academic activities using a computer software in a fun, novel, and challenging way (Khazanchi, & Khazanchi, 2020).

Cogni-PreLit App

The Cogni-PreLit Web App was developed under the scope of stimulating core components of EF and enhancing preliteracy skills in high ability learners, based on evidence of their bidirectionality. It is an educational training software of three Efs: inhibition, WM and cognitive flexibility with embedded preliteracy activities and infused with game-like elements, which can be used in the classroom to meet the diverse needs of Greek high ability preschoolers. Additionally, the provided different levels of difficulty allow its use in the first-year primary school children as well.

Technical specifications

The Cogni-PreLit is built with PHP7 and JavaScript over a MySQL database for data storage and 256-bit AES encryption. Both the database and the code are built with one of the most important considerations being scalability. Scalability is essential even though it increases complexity and difficulty for the completion of the Web App, because it allows for easy future expansion both in the quantity and quality of the games as well as their features. At the moment, it includes 13 training modules with 33 games, out of which 16 games target the core Efs (inhibition, WM and cognitive flexibility) with embedded PA exercises. The rest of the games tap only PA and hierarchically include rhyming (judging whether two words rhyme), alliteration and matching rhyme, syllable blending and splitting, full phoneme segmentation and manipulation (deleting, substituting). These preliteracy activities always precede the Efs

games in each module and straight afterwards they become the medium for training the three core Efs.

Application interface

The Cogni-PreLit App runs on a PC or a mobile device. At the moment, registration is unavailable as Cogni-PreLit is in closed Beta version. Pre-registered teachers can log in with their credentials and access all app functionalities. These provide the ability to enroll new students (including full name, father's name, date of birth, name of the school and year) and view a list of all enrolled students (Figure 1).

Figure 1. Log in & Students' enrolment

After enrolling students, the teacher can select the student that he/she will train and enter the Game Selection Interface (Figure 2).

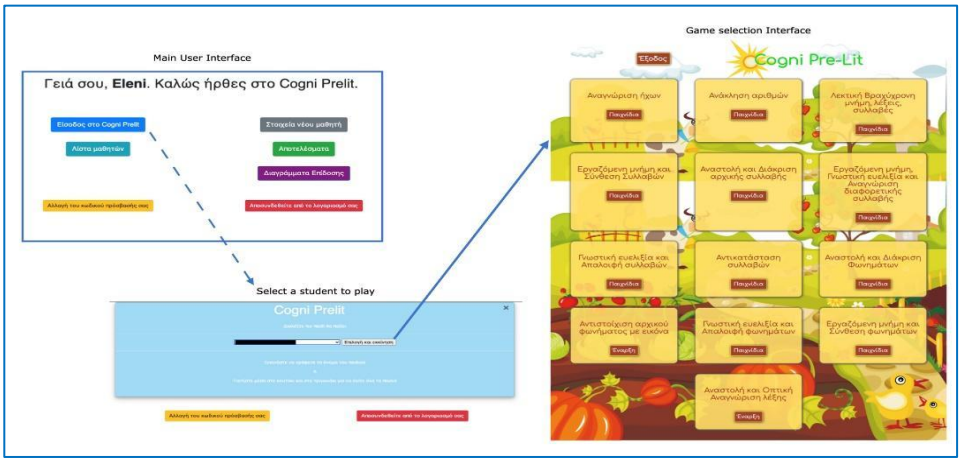

Figure 2. Game Selection Interface flow

Data from each training session are stored in the database. It includes the name of the game-task, the chosen stimuli, the time provided for an answer, the game rounds, the number of wrong answers or time-out, the total played time, the average round time, the date and time of game completion and the percentage of correct answers. Based on these data, online feedback is received about the child's progress on the training task. Through the Main User Interface, the teacher has access to the Student's Score Interface with all the aforementioned data. It allows to search any student by name and download the results in Excel, CSV or PDF format. Moreover, access to the student's progress diagram is provided. To access the student Progress Diagram Interface, one must first select the student. Then, he/she can select a specific game-task progress diagram or the overall progress diagram. Downloading of the viewable diagram is also available in a JPEG format (Figure 3).

Figure 3. Students' Scores & Progress Diagrams

Gameplay

The games are based on classic tests of Efs performance. Training modules are presented as games that record the performance of the preschooler based on the accuracy and response time in each phonological and cognitive skill. They are introduced in a hierarchical PA order, with different levels of difficulty according to the number of stimuli, which in our case are audio files of words, syllables and phonemes. In addition, the time of on-screen appearance of objects, related to the game sounds, is also used to define different levels of difficulty. Practice trials are included in each game and precede the actual tasks. Taking into consideration that preschoolers' performance varies within EF training tasks (van Bers et al., 2011) and the fact that WM training seems to be most effective in the short term (Orylska et al., 2019), when the child achieves a score of 70-75% or more in each task, we increase the level of difficulty in the following session, either by increasing the number of stimuli or by decreasing the allowed response time.

The game-world of Cogni-PreLit is an animal farm, where different animals live and appear as the main characters-narrators of each game to sustain children's engagement. All animals living in the farm either have a problem and ask for help or invite the children to play with them. At the beginning of each game, the main character-narrator offers audio instructions along with a visual demonstration. In between stimuli, the child is provided with a subtle feedback sound, depending on whether the answer is correct or wrong. When the task is concluded, the user is awarded a trophy accompanied by a cheerful sound.

An example of the Cogni-Prelit games, targeting working memory with embedded initial syllable sound identification task is described as follows:

Scabby the dog appears on the screen and in a pre-recorded voice says: "*Hi! My name is Scabby and we will play together. Next to me, you see three objects. Here you see '**ma**yio' (Greek word for swimsuit), here you see '**ro**di' (Greek word for pomegranate) and here you see '**ma**ti' (Greek word for eye). '**Ma**yio' and '**ma**ti' sound the same in the beginning. '**Ro**di' has a different sound in the beginning and you should touch it to make it disappear.*" (Figure 4a). Scabby continues with the second set: "*Here you see '**ka**pelo' (Greek word for hat), here you see '**he**rouli' (Greek word for door handle) and here you see '**ka**seri' (Greek word for cheese). '**He**rouli' has a different sound in the beginning and you should touch it to make it disappear* (Figure 4b). *Now you have to tell me the two different words together, with the same order they appeared*".

The child should say *'Rodi, Herouli'*. The instructor now has to press the right arrow for the correct answer or the left for the wrong one (Figure 4c). Three practice trials precede the actual task in this particular game which consists of 6 rounds. Three difficulty levels exist, starting from a set of two words to a set of four words to recall. The time provided for an answer can range from 10s to 60s and is used as well as to define difficulty level. Another game, practicing in initial syllable sound identification, precedes this particular game according to the protocol of Cogni-PreLit.

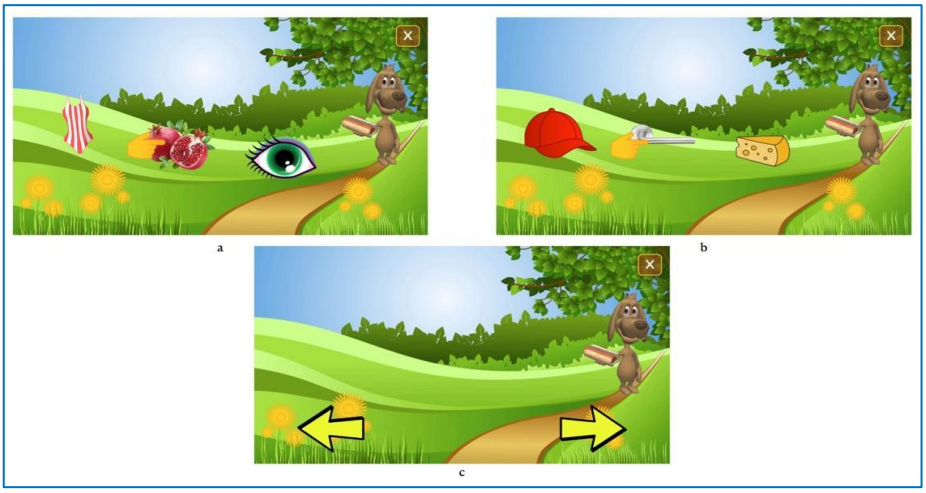

Figure 4. Working memory game embedded with initial syllable sound identification task

Conclusion

Stimulating early executive functions lays the foundation for future formal literacy. Indeed, Efs coordinate the cognitive and behavioral processes while children are learning to read. Cogni-PreLit was developed to meet the needs of high ability preschoolers, whose education requires acceleration, enrichment, and in-depth teaching of material to meet their diverse needs in the classroom. A current and ongoing research into the efficacy of the Gogni-PreLit app as a school-based implementation to empower the Efs and preliteracy skills in a group of high ability preschoolers has been delayed due to the Covid-19 pandemic. However preliminary findings are promising for its potential use as a cognitive acceleration program. By addressing Efs skills with embedded preliteracy activities, high ability preschool children, who manifest a great variability on neuropsychological and academic measures within their population, will be better prepared for the transition to formal literacy education in first grade.

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