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PAPER

# Implementing a Web Application Screener for Preschoolers: Executive Functions and School Readiness

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## ABSTRACT

Web applications can be constructed to assess the executive functions and literacy skills of preschool aged children using a variety of research protocols. This work describes such a web application and its research protocol with tasks that screen inhibition, auditory and visual working memory, letter sound connection, word identification, and cognitive flexibility. The application was tested on a group of 65 preschoolers with cognitive deficits whose parents were advised to allow their children to reattend kindergarten classes and a control group of 65 typically achieving peers of similar age and gender. The results revealed that children at the age of four and five years old with cognitive deficits presented lower scores of correct answers and larger latencies in all six tasks compared to children that participated in the control group.

## KEYWORDS

preschool children, web application screener, school readiness, executive functions

## 1 INTRODUCTION

Children's executive functions (EFs) develop rapidly throughout the first five years of life because they must learn to change their behavior in order to override automatic or ingrained ideas and responses [1]. Infants go through physical and cognitive changes. Infants' brains develop more quickly than any other part of the body, and by the time they are five years old, they weigh around 90% as much as an average adult brain does [2]. The two hemispheres of the brain begin to differentiate and they specialize in various tasks. The preschool years are when cerebral laterality becomes more apparent. It is backed by the fact that preschoolers' improved cognitive skills are correlated with both brain growth and the amount of myelin covering

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their brain neurons. The brain regions with the slowest rate of development, the prefrontal and frontal cortex, have been intimately associated with EFs.

In order to lay a crucial foundation for the development of higher cognitive processes far into later life stages (such as adulthood), core EFs emerge during the preschool years [2]. The various prefrontal cortex regions are closely linked to the various aspects of goal-oriented behavior [3]. Several studies have presented that the prefrontal cortex, which is in charge of EF development, increases noticeably during early childhood development. As a result, the fundamental elements that compose and serve as a key foundation for the formation of EFs can be identified even in children as young as four years old [2][4].

The emergence of nearly all cognitive, behavioral, and social-emotional functions occurs during sensitive times of fast brain development in infancy and early childhood [5]. The process of myelination, dendritic arborization, synaptogenesis, and synaptic pruning occurs during this time, shaping and honing the brain's expressive networks [6]. The brain activity that controls these adaptive processes makes them responsive to external, genetic, hormonal, and other stimuli [7]. The development and the pattern of myelination follows a well-described neuroanatomical arc, progressing from a posterior to anterior and center-outwards spatiotemporal pattern that corresponds to maturing cognitive functions [7]. The myelination of the brain areas and networks supporting a given cognitive function and its emergence share a lot of similarities [8]. Many studies in this field demonstrate the significance of white matter and cortical myelination for cognitive development and brain plasticity (e.g. [9]).

The rest of this paper is organized as follows. Section 2 discusses EFs in detail, focusing on their assessment, particularly through computer-based tests. Section 3 presents the testing methodology used in this research. The results obtained are presented and analyzed in Section 4. Final discussion and conclusions are given in Section 5.

## 2 EXECUTIVE FUNCTIONS AND THEIR ASSESSMENT

### 2.1 EFs

Although EFs are frequently discussed in neuropsychological studies, there is still no official definition of them. Contradictory results from studies examining the various facets of this construct have frequently been obtained, leaving uncertainty and even dispute over the genuine nature of executive talents [10]. The word "EFs" refers to a broad range of cognitive processes that help with goal-oriented behavior by controlling and coordinating information [11]. A more comprehensive definition of EFs refers to a family of top-down mental processes required when one needs to concentrate and focus attention in situations where depending on instincts or intuition would be unwise, insufficient, or impossible [12].

Despite their complexity, there is a general understanding of the complexity and significance of cognitive functions for adaptive behavior in humans. Cognitive skills enable attention shifting and adaption to a variety of events in a continually changing environment, while also thwarting inappropriate behavior [10]. Inhibition, attention shifting, updating, fluency, and planning are just a few of the higher order cognitive processes that are involved in the complex construct known as EFs.

The ability to control a response—or lack thereof—to a stimulus is referred to as inhibition. The capacity to switch from one job to another is shifting. The ability to monitor and control mental representations held in working memory is referred to as updating. Fluency is the capacity to produce a predetermined number of words in a predetermined amount of time based on semantic categories or phonemes. The ability to conceive, assess, and choose a series of ideas in order to accomplish a goal is referred to as planning.

The idea that EFs develop in a hierarchical fashion with attention serving as the basis is put forth by several studies that look at the development of EFs from infancy to the age of five years (e.g. [2]). According to early developmental EF studies, it is hypothesized that early simple skills like remembering information and delaying a response during the first three years of life create the foundation of their character [13]. According to the constructivist model of cognitive development, it is maintained that these simpler components combine into more complicated processes including inhibition, working memory, sustained attention, planning, rejecting distractions, and shifting that define mature EF abilities [3][14]. In accordance with this idea, Garon et al. hypothesized that more complex abilities that develop later such as shifting and planning are constructed from earlier abilities. For instance, shifting requires working memory and inhibition in addition to the ability to shift [13].

Many studies suggest that EF skills are essential for children's academic success from early infancy to adolescence [15][16][17][18]. Since the child is once again required to participate in regulated activities in a formal setting that call for self-control during the transition to kindergarten, a successful adaptation to kindergarten is a crucial developmental cornerstone. Pre-literacy and mathematical reasoning are influenced by executive functions more than IQ in terms of preparedness for the first grade, according to studies [19]. Research indicates that from elementary school through high school, working memory and inhibition each independently predict success in arithmetic and reading. As a result, it has been asserted that EFs are crucial for academic success across all school years [19].

The academic outcomes of kindergarten were predicted by preschoolers' levels of inhibition and cognitive flexibility, according to research that followed Head Start preschoolers through kindergarten. In another study including Head Start toddlers, it was discovered that EFs could predict improvements in math, vocabulary, and listening comprehension throughout the preschool years [20]. Furthermore, throughout this period of life, emergent literacy skills, including detection of letters and letter sounds, manipulation of phonemes and identifying words can predict early reading development and subsequent reading accomplishment [17]. Studies have demonstrated that children who start school with impairments in language and emergent literacy skills later commonly develop reading problems as well as underachievement in middle school and beyond [17].

## 2.2 Assessment of EFs

There are several paper pencil tests that assess executive functions and reading abilities of preschoolers to identify their school readiness. For example, in order to assess inhibition skills, the developmental neuropsychological assessment test NEPSY-II has an inhibition assessment subtest [21]. Furthermore, Wechsler Preschool and Primary School Scale of Intelligence IV includes subcomponents that assess working memory [22]. Cognitive flexibility can be measured by the semantic verbal fluency subtest that is included in Coimbra Neuropsychological Assessment Battery [23], according to Diamond [24][25]. Well-studied assessments of phonological awareness, phonological access, letter knowledge and print awareness are sub scales of the Preschool Comprehensive Test of Phonological and Print Processing [26].

The use of computer-based neuropsychological assessment has been significantly increased in clinical diagnosis practice across a variety of specialties, including the evaluation of neuroscience and cognition learning disabilities [27], human computer biological signals interaction [28], and neurologic patients [29]. It is possible to precisely control variables for measuring cognitive functions, such as reaction time, correct or incorrect responses, error types, and the administration of direct stimuli, when using computer-based neuropsychological assessment to diagnose various clinical disorders in neuroscience [27]. Children today appear to be more engaged in their education, since they have access to electronic tools to help them with their homework [27]. Information and communication technologies (ICT) in education can improve the effectiveness and efficiency of teaching and learning because they entail learning using technology rather than just learning about it [30]. A vital initial step in the effective prevention of developmental and socioemotional difficulties is the early detection of speech, language, and behavioral impairments or delays, and young children's cognitive and linguistic development has an impact on subsequent development and readiness for learning [27][31]–[36]. The best studied computer-based assessment for preschool aged children is CoPS. CoPS is constructed on eight test tasks: a task that assesses visual sequential memory for spatial and temporal positions, a task that assesses visual memory for colors, a task for visual sequential memory for shapes and colors, a task for visual sequential memory employing letter-like symbols, a task that assesses letter names and none word names, a task that assesses auditory memory, a task for phonological awareness and a task for auditory discrimination phonemes. CoPS is used mainly for cognitive assessment and reading development [37].

### 2.3 Motivation and present study

In the present study, in order to assess EFs of preschoolers, a battery of test tasks was constructed in order to assess their inhibition ability (by a go/no-go task), as well as their visual and auditory working memory and their cognitive flexibility (by a visuospatial task). Furthermore, apart from the core, two additional tasks of school readiness were designed across the two main domains as an assessment of reading abilities, by including a letter–sound correlation task and a word identification task [38].

In the field of assessment of cognitive functions of kindergarten-age children, web applications do not exist, to the best of our knowledge. The main goal of the present research protocol was to construct a battery of tests that can be delivered by internet in order to screen cognitive functions and literacy skills of preschool children. This type of computer technology can be used nearly everywhere because it can be automatically installed on any device with a web browser.

Since it is cross-platform by nature, there is no action required from the user in the event of an update. A web application also doesn't need proprietary software that restricts it to a certain platform and has a quick development cycle, making it easier to build and deploy than ordinary desktop applications. In addition, the size of the community makes it possible to consider new functionalities to address growing issues quickly.

The hypothesis of the present study was that Greek preschoolers that are already diagnosed by paper-and-pencil tests with cognitive deficits whose parents were advised to allow their children to reattend kindergarten classes, will also present lower performance and higher time latencies in both cognitive and reading tasks of the web application screener.

## 3 RESEARCH METHODOLOGY AND IMPLEMENTATION

### 3.1 Participants

A total of 130 preschoolers participated in this study. More specifically, the children recruited were 69 males four and five years old (M = 4.41 SD = 0.449) and 61 females four and five years old (M = 4.79 SD = 0.415). The preschoolers with cognitive deficits (N = 65) had been diagnosed by paper-pencil tests by the psychological service of the Center of Diagnosis, Assessment and Support in Central Greece (as required by Greek Law) and their parents were advised to allow their children to reattend Kindergarten classes. The control group (N = 65) was formed by randomly selected infants who attended the same Kindergarten with their average peers. They presented typical academic performance according to their teachers' ratings. All preschoolers that participated in the present study did not have a history of major medical illness, psychiatric disorder, or significant visual or auditory impairments according to their medical records kept by the kindergarten. The participants of the comparison group were matched for age and gender with preschoolers with cognitive deficits (1 cognitive deficit: 1 control).

All participants were recruited after reading informative newspaper articles, notifications regarding inside schools and attending informative school meetings. All participants were selected from the region of Central Greece and took the test at the computer laboratory of the Department of Informatics and Telecommunications of the University of Thessaly. Preschoolers with cognitive deficits completed the test in thirty minutes on average and typical achieving participants completed the screening procedure in twenty minutes on average. All human data included in this manuscript were obtained in compliance with the Helsinki Declaration and the guidelines of the Ethics and Deontology Committee of the University of Thessaly.

### 3.2 Material and procedure

A battery of six tasks was used to test each participant's inhibition, auditory and visual working memory, letter-sound association, word identification, and cognitive flexibility. Children undertook one training activity to become familiar with the testing technique before starting the main test procedure. Children had to click a picture in the practice activity in order to operate the mouse and become accustomed to the action.

The six tasks are described next:

**a)** Inhibition task: Children had to choose the target picture out of five that were given randomly in the task during the test. The target pictures were presented four times and the non-target pictures were presented ten times (see Figure 1).

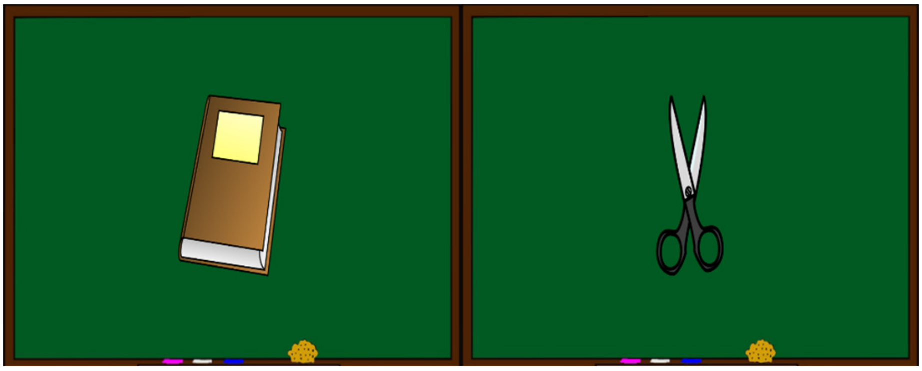

**Fig. 1.** Go/no-go task. Target picture (book), non-target e.g., scissors

**b)** Visual working memory task: Preschoolers had to remember 22 sequences of numbers during this task. The first sequence included three numbers; the second four numbers; the third five numbers; the fourth six numbers; the fifth seven numbers; the sixth eight numbers. Participants were asked to report the numbers with the use of a 0–9 numerical pad that was displayed. It is worth to mention that if children could not remember two series of numbers in a row or three series of numbers in general, the task was stopped (see Figure 2).

**c)** Auditory and Visual working memory task: This task consisted of twenty two sequences and was similar to the visual memory task, but the number sequences were given auditorily (see Figure 2).

**d)** Letter-sound task: Children had to select the phoneme that was auditorily delivered (10 phonemes) out of three graphemes.

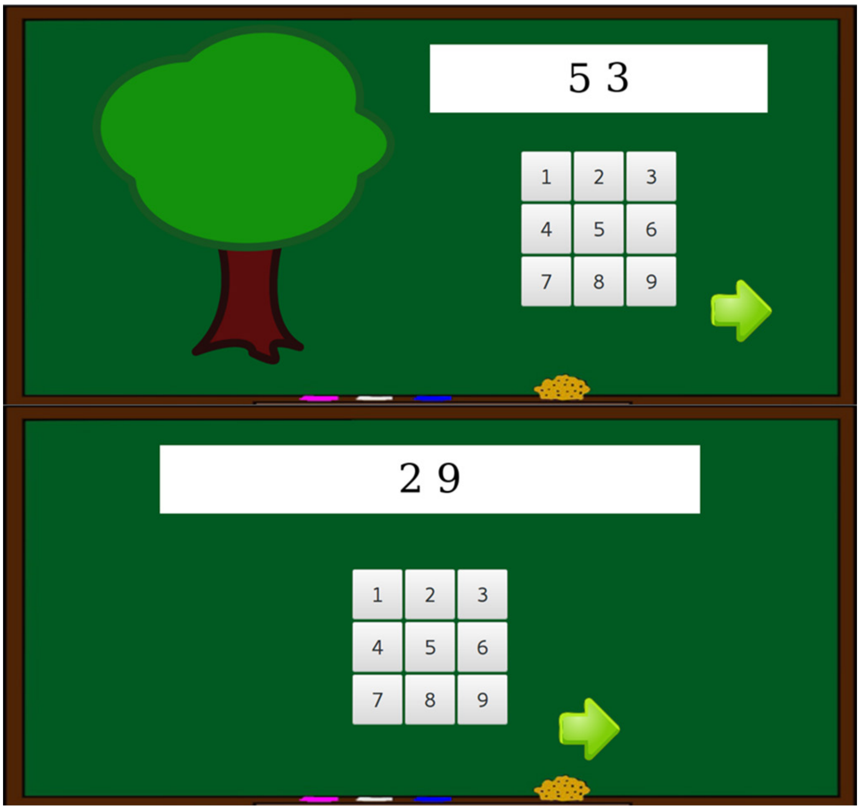


**Fig. 2.** Visual (upper part) and auditory (bottom part) working memory task

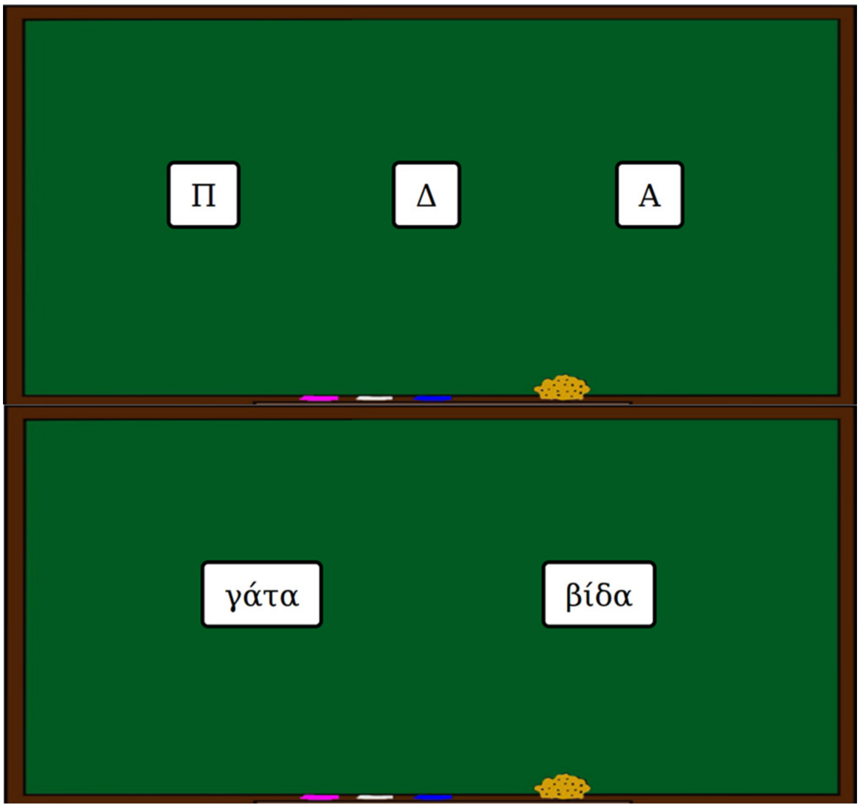


**Fig. 3.** Letter sound task (upper part) and word identification task (bottom part)

**e)** Word identification task: Children had to listen to a word (10 words in general) and decide which was the correct between two words that were presented. It must be highlighted that the words presented auditorily were commonly used and consisted of two syllables (see Figure 3).

**f)** Cognitive flexibility task: This assessment comprised a series of ten diagrams or patterns with a part missing and children were expected to select the correct part to complete the designs out of three options (see Figure 4).

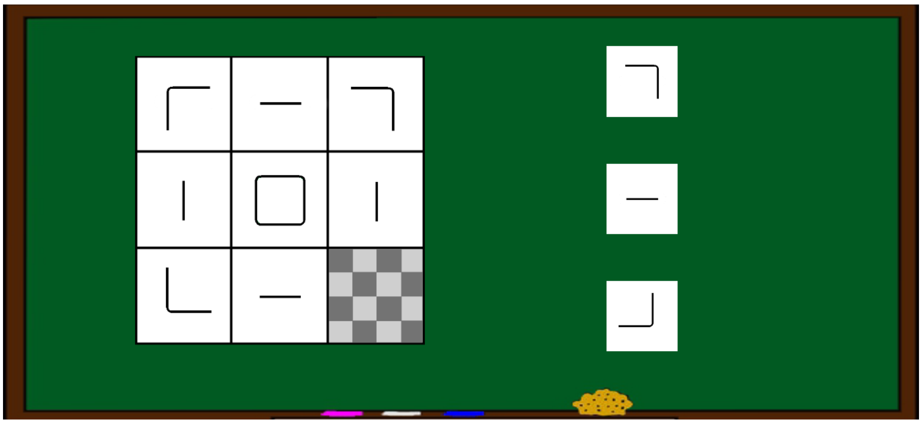

**Fig. 4.** Cognitive flexibility task. Pattern with a missing part in which children have to choose the correct from the three that are presented on the right

It is important to point out that every preschooler was able to operate the program successfully. From the first training task to the final testing procedure, they were able to operate the program with ease and efficiency because, prior to the assessment tasks, an illustration of the requirements of the subsequent process was provided to the kids.

Only technical concerns, such as entering the web application's URL, were made by the researchers.

### 3.3 Implementation

We deployed a client-server web application to provide a guided learning experience to students and to facilitate users with a unique browsing experience. Since our web application can be accessed by multiple users simultaneously, there is a constant communication demand between clients and the server that hosts the web application. To be more precise, every time a student finishes all six tests, all the intermediate results along with his/her basic personal information are saved for further inspection. Based on that, we select a minimum set of web technologies considering the maintenance, the reliability, and the performance of our web application. More specifically, for the client-side (frontend) we select HTML5, CSS3 and JavaScript to provide a user-friendly interface, while for the server-side (backend), we select PHP and MySQL to handle data storage and application logic.

HTML is the main markup language used for presenting and structuring content in a website. Its fifth version (HTML5) supports responsive design for mobile users, better performance for a website and compatibility between browsers. Moreover, the introduction of new tags replaces the need for installing third-party plugins for audio and video features while it replaces code snippets from other programming languages frequently used by web developers. For the beautification of our web application, we used Bootstrap. Bootstrap is the most-popular CSS framework for developing responsive web designs as it includes HTML and CSS design templates for typography, navigation, buttons, and forms. We select a color representation, keeping in mind simplicity to avoid confusing users, using green and white colors. We also used the same color palette for each test while we add contrast to draw attention to certain parts of the page. The core functionality of our application (i.e. screening tasks) was implemented using Vue.js that is a progressive JavaScript framework for building front-end interfaces. In Vue.js, a user can start a simple web page and progressively add tools and features that are needed for a demanding and complex web application like the one presented in this work. It also provides a way to build components that encapsulate data or a state on the JavaScript and then connect that state reactively in a template in HTML.

The back-end of our web application consists of a server, an application and a database. We used the PHP programming language to generate dynamic page content and to handle the communication between the client and the server. With PHP we managed to authenticate users using sessions and cookies that is one of the cornerstones of web security. Different capabilities were given regarding the role of each user. For instance, students can only enter their personal information and answer the relevant tasks, while the administrator can inspect preschooler scores, add new schools, create new classes etc. PHP also includes database support. Thus we select the MySQLi PHP extension to connect to a MySQL server. Using the appropriate queries, we save student answers into the database to be used for statistical analysis. Our web application has been enhanced to protect and secure sensitive information that is passing through different types of online channels. To achieve this, we implement secure SQL statements by using escaping and prepared statements, we support input validation using data type, format and value validation from both front-end and back-end using JavaScript and PHP respectively, and we apply multi-factor authentication and access control (e.g. a student is logged out when he/she tries to access more sensitive features). As current privacy regulations require the protection of sensitive data, we encrypt user personal information and student answers. To achieve that we encrypt sensitive information using a strong one-way hashing algorithm. The adaptive bcrypt password-hashing function was selected which adds a random salt to prevent rainbow tables and dictionary attacks. Finally, all data exchanged between clients and server were encrypted using the HTTPS protocol.

### 3.4 Data analysis

Descriptive statistics were performed in order to obtain mean scores and standard deviations of participants for all six tasks, as the training test was excluded from the statistical analysis. Prior to performing any statistical analysis, a Kolmogorov-Smirnov test in order to find the normality of collected data, as well as a Levene's test for homogeneity of variances were calculated. Analysis of Variance was the statistical analysis that was selected, due to the sample of the participants (N = 130) and their splitting in two groups.

## 4 RESULTS

Analysis of Variance (ANOVA) was conducted to compare the scores of children according to their group. Table 1 presents the mean scores and standard deviations for the correct responses to the six tasks. Furthermore, the table presents time latency and the statistical significance of the correct answers and time latency of children with cognitive deficits versus the control group. It must be highlighted that in inhibition tasks, visual and auditory working memory tasks latency was not measured.

**Table 1.** Mean scores and standard deviations of correct responses and time latency in seconds with the associated statistical significance for all tasks

| Tasks | Groups | | | | F |
|---|---|---|---|---|---|
| | Children with Cognitive Deficits | | Control Group | | |
| | Mean | SD | Mean | SD | |
| Inhibition Task | 1.11 | 1.13 | 2.38 | 0.93 | 49.284* |
| Visual Working Memory Task | 0.68 | 0.66 | 1.15 | 1.31 | 6.923* |
| Auditory Working Memory Task | 1.77 | 1.64 | 4.15 | 0.87 | 106.556* |
| Letter Sound Connection Task | 4.20 | 0.93 | 6.09 | 1.11 | 83.588* |
| Letter Sound Connection Task Latency | 0.64 | 0.51 | 0.45 | 0.26 | 7.154* |
| Word Identification Task | 5.44 | 1.25 | 7.15 | 1.36 | 34.497* |
| Word Identification Task Latency | 0.45 | 0.39 | 0.22 | 0.87 | 21.382* |
| Cognitive Flexibility Task | 4.45 | 0.88 | 5.15 | 1.03 | 19.192* |
| Cognitive Flexibility Task Latency | 1.32 | 0.51 | 1.20 | 0.47 | 1.292 |

*Note:* *$p < 0.01$.

ANOVA revealed that children with cognitive deficits had statistically significant ($p < 0.01$) lower mean scores of correct answers in all six tasks compared to the control group. It must be noted that children with cognitive deficits presented statistically significant ($p < 0.01$) higher time latency in seconds for letter-sound connection and word identification tasks in comparison to children that participated in the control group. Although children with cognitive deficits presented higher time latency in seconds in cognitive flexibility in comparison to children that were recruited as control group, we did not find statistically significant results ($p > 0.05$). It must be mentioned that in inhibition task, auditory and visual memory tasks time latencies were not calculated.

EFs develop particularly rapidly (as early as infancy) and undergo protracted development into early adulthood as well as during the critical age period that was examined. Because of the above, researchers decided to apply ANOVA to groups of children according to their age. In more detail, it compared children of 4 years of age with cognitive deficits only to their average peers and children with cognitive deficits of 5 years of age to their respective average peers. The analysis revealed that both groups of children with cognitive deficits presented statistically significant ($p < 0.01$) lower scores in all six tasks in comparison to the control group. Also, they presented statistically significant larger latencies ($p < 0.05$) in the three tasks for which the time latency was recorded. Lastly, Cronbach's alpha was measured in order to find the internal consistency of all six tasks (not for latency) and was estimated $\alpha = 0.77$.

## 5 DISCUSSION

The web application screener that was used revealed significant differences ($p < 0.01$) in all six tasks that were constructed between preschoolers with cognitive deficits and the control group. In more detail, preschoolers with cognitive deficits presented statistically significant lower scores in comparison to the control group, a result that verifies our first hypothesis. Furthermore, preschoolers with cognitive deficits presented larger latencies in all three tasks for which time was recorded, in comparison to the control group, but the statistically significant latencies ($p < 0.01$) were observed during the letter sound connection task and word identification task, whereas the latency of cognitive flexibility task did not present significant differences between the two groups of children. The latency of cognitive flexibility task might be affected by the complexity of the diagrams and patterns that were chosen, as participants in both groups had difficulties in choosing the correct answer. This result partly verifies our second hypothesis.

However, it must be noted that through separation according to age (only children of four years of age and five years of age with cognitive deficits and their respective comparison group), it was observed that children with cognitive deficits presented statistically significant lower scores ($p < 0.01$) in all six tasks and statistically significant larger latencies in three tasks for which time was recorded ($p < 0.05$) in comparison to their average peers.

EF and school readiness skills are of utmost concern. In order to effectively promote school success for all children, it is necessary to better understand the underlying factors which contribute to early lapses in school readiness. The purpose of the current study was to present the relation between EFs of preschoolers and academic readiness. The results confirmed our hypothesis for correct answers and partly for higher latencies.

The fact that children with cognitive deficits can be screened for using a computer-based neuropsychological testing that is administered online was another significant finding of the current study. Computers are increasingly being used in psychology and education to identify children with EF problems. The main benefit of computer-based systems over traditional diagnostic techniques is the accuracy of the evaluation of cognitive abilities. Computers can significantly reduce the amount of time and effort required by scoring performance in terms of accurate or erroneous answers as well as time lag [30].

In a meta–analysis Sala and Gobet showed that training studies based on working memory intervention led to improvement in working memory [44]. Motivation likely plays a crucial role in determining training success. Previous research has shown better training success in children with gamified designs [45][46]. Web applications could be beneficial not only in screening but also as intervention programs by targeting the "players" motivation with training core mechanisms of EFs [27][47].

A diagnosis made by a qualified professional, or even better, by a multidisciplinary team of experts with a variety of talents, such as psychologists, educational diagnosticians, or other licensed professionals, cannot be totally replaced by a web-based exam screener. It is preferable for an efficient assessment of a student's abilities, limitations, level of academic performance at the time and eligibility for special education services. The interdisciplinary team that may conduct assessments may also design the intervention program that kindergarten students and infants with low academic success must adhere to [38][48]. The web-based screeners, on condition that are valid, can only be a supporting tool at the diagnosis.

In reviewing the findings of this investigation, the reader should bear in mind some of the study's methodological limitations. First, despite the fact that all participating preschoolers with cognitive deficits had received a formal diagnosis from a state diagnostic facility, the study team was unable to access their results of the diagnostic tests due to the applicable data privacy legislation. Furthermore, causality conclusions should be avoided because the data were collected at a single time-point. To confirm these results, answer the causation query, and determine whether one process influences another over time, more longitudinal study is necessary. Second, we tried to design and implement a web application that measured EFs and pre-literacy abilities of preschoolers drawn from theoretical models and did not use well-established paper pencil tests in order to combine our findings.

In conclusion, the pre-literacy and EF web application screener created and employed for the current research protocol can be used as a screening tool to give first-pass service and referral. Additionally, this research supports previous findings that children with low academic achievement have problems not only with language skills but also with more fundamental capabilities like cognitive ability. Before its general adoption can be advised, the screening technique must also undergo a rigorous psychometric evaluation, the validity of the results of which are now being developed.

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