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Executive Function evaluation in children with learning disabilities through a tablet assessment battery

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Abstract

Executive functions are a set of psychological processes that are necessary for the cognitive control of behavior: selecting and successfully monitoring behaviors that facilitate the attainment of certain goals. These skills are necessary to guide learning of new information. Core executive function (CEF) are inhibitory control, working memory and cognitive flexibility. They regulate and control other skills and behaviors, and also have influence on more basic skills such as attention, memory systems, and praxis. Executive functions allow setting goals and carrying them out through planning and monitoring, keeping inhibited thoughts, behaviors and emotions that interfere. This research consists of determining neuropsychological EF profiles in different clinical populations evaluated with tablet-based test. Two batteries developed by CEDETI UC were applied: Yellow Red and TENI (Infant Neuropsychological Assessment Test). The sample consists of 175 argentine children, between 7 and 12 years old, divided in two groups, clinical and control. The obtained scores show the importance of distinguishing profiles between these three CEF within the clinical population comparing with a typical developing group. The overall index obtained differentiates the groups best. Children with dyscalculia, autistic spectrum disorder and borderline intellectual disability obtain significantly lower scores having greater difficulties in EF.
Keywords*:* Executive functions; neuropsychological assessment; learning disabilities; tablet

Evaluación de Funciones Ejecutivas en niños con dificultades de aprendizaje a través de una batería en formato digital

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Resumen

Las funciones ejecutivas permiten plantear metas y llevarlas a cabo a través de la planificación y el monitoreo de su desarrollo, manteniendo inhibidos pensamientos, comportamientos y emociones que interfieren. Son habilidades necesarias para guiar los procesos que permiten el aprendizaje de nueva información y están constituidas por el control inhibitorio, la memoria de trabajo y la flexibilidad cognitiva. Controlan y regulan otras habilidades y conductas, e influyen en habilidades más básicas como la atención, los sistemas de memoria y las praxias. Este trabajo de investigación consite en determinar perfiles neuropsicológicos en diferentes poblaciones clínicas a través de la aplicación de baterías de evaluación neuropsicológica en formato digital, que evalúan distintas funciones ejecutivas. Se aplicaron dos baterías desarrolladas por CEDETi UC: Yellow Red, y TENI (Test de Evaluación Neuropsicológica Infantil). La muestra consta de 175 niños de ambos sexos, entre 7 y 12 años, divididos dos grupos, clínico y control. Los puntajes obtenidos permiten determinar perfiles neuropsicológicos dentro de la población clínica. El índice global obtenido es el que mejor diferencia los grupos. Los niños con discalculia, trastorno del espectro autista e inteligencia límite obtienen puntajes significativamente más descendidos presentando mayores dificultades en las funciones ejecutivas.
Palabras clave: Funciones ejecutivas; evaluación neuropsicológica; dificultades de aprendizaje; tablet

Introduction

Executive Functions (EF) comprise those skills that allow us to set goals and carry them out through permanent planning and monitoring during their development, keeping inhibit thoughts, behaviors and emotions that interfere with the achievement of their objectives. EF are critical to success in school, work, and in life. They are essential to carry out a reasoning, solve a problem, understand what we read or hear in a class, choose to be creative and self-regulate and flexibly adjust the information we receive (Burgess & Simons, 2005; Diamond, 2013; Espy et al., 2004; Miller & Cohen, 2001). EFs are needed when we have to concentrate and think, when acting on our initial impulse, relying on instinct or intuition, or going on automatic would be ill-advised, insufficient, or impossible. EFs depend on a neural circuit in which the prefrontal cortex plays a prominent role (Braver & Barch, 2002; Champod & Petrides, 2007; Miller & Cohen, 2001; Zanto, Rubens, Thangavel & Gazzaley, 2011).

EF are regarded as an umbrella term for top-down mental processes, which are necessary for all types of cognitive performance (Diamond, 2006; Diamond, 2013). EFs are able to predict the overall academic performance of student over time.

Core EF are formed by three specific cognitive abilities or functions: *working memory*, *inhibition* (self-control, resisting temptation and resisting acting impulsively) and *cognitive flexibility* (including creativity) seeing anything from different perspectives and quickly and flexibly adapting to changed circumstances (Diamond, 2013; Santa-Cruz & Rosas, 2017).

Working memory (WM) is the ability we have to hold in mind and mentally manipulate information over short periods of time. It is often thought as a mental workspace that we can use to store important information in the course of mental activities (Gathercole et al., 2008). This ability increases with age, and is essential to establish relationships between previous knowledge and new information (Carriedo, Corral, Montoro, Herrero, & Rucian, 2016), to establish non-obvious connections and to understand different types of expressions (Diamond, 2012; 2013). A sufficient capacity should have been acquired at the beginning of school to operate with the complexity required by the contents, particularly those related to learning the symbolization systems necessary to decode and to learn the numerical systems (Santa-Cruz & Rosas, 2017).

Inhibitory Control (IC) is the ability to ignore dominant, automatic or prepotent response that are irrelevant to task processing. It allows an individual to stay focused on the main task and prevents him from making automatic responses that do not fit the situation (Diamond, 2013). It distinguishes between cognitive inhibition, which is the control of emotions, thoughts and feelings that interfere with the course of thought or activity in the WM, and behavioral inhibition, which is the control exercised over actions. It directs consciously the attention, the course of thought, behavior and emotions. It has the effect of canceling both internal predispositions and the effect of the environment, which could lead us to carry out another task. Essentially, it consists of the ability to inhibit alternative thoughts, emotions and behaviors that distract us from the current task. It is therefore an attentional control measure (Diamond, 2013; Friedman & Miyake, 2004; Santa-Cruz & Rosas, 2017).

Cognitive Flexibility (CF) is the ability that allows an individual to adjust to the demands of the environment efficiently (Miller & Cohen, 2001), creating and using alternative problem-solving strategies. In this sense, it allows a certain situation to be observed from multiple points of view (Diamond, 2012), changing behaviors directed towards a specific goal, the attentional focus or varying strategies according to the stimulus (McGowan et al., 2018). This skill includes a strong socio-affective component, as it includes the ability to understand solution strategies or understanding solutions that other people use. It is, therefore, a skill of both a cognitive and an affective nature. It has to do with empathy and creativity generating new solutions to solve a problem. (Santa-Cruz & Rosas, 2017). CF is also called set shifting, mental flexibility or mental set shifting, and it is built on WM and IC and it allows to change perspective and strategy to adjust to changes in external demands and take advantage of emerging opportunities (Diamond, 2012; 2016).

EFs monitor and control all behavior, and not just cognitive problem solving. The long and complex process of the development of the prefrontal cortex is related to the regulation of one's own emotions and social adequacy (Santa-Cruz & Rosas, 2017).

The evidence indicates that, from the age of 7, EF is progressively defined. Not until adolescence are children able to solve complex shifting tasks (Santa-Cruz & Rosas, 2017) nevertheless basic forms of CEF can be observed already in preschool years.

EF have an accelerated development during childhood, between the first and sixth year of life.

Also, a large body of research present evidence of a significant predictive effect of EF and academic performance (Reyes, Barreyro e Injoque-Ricle, 2015) and the importance of EF in learning processes (Fonseca, Rodríguez y Parra, 2016).

These studies evidence the relationship between cognitive skills and literacy learning and mathematical competences (Orbach, Herzog & Fritz, 2020; Risso et al, 2015)

The preschool stage represents a window of opportunity for intervention, enhancing the development of EF during childhood. This stage also has the advantage of being able to intervene through educational proposals in those children who, given the conditions associated with their SES, see the development of their EFs limited. It is from this perspective that preschool education has been proposed as a space where the development of skills and knowledge that facilitate the acquisition of learning in the later stages of schooling and subsequent socialization should be promoted (Blair, 2002). A series of studies has been found that relate the development of certain cognitive abilities with the subsequent development of executive functions, such as attention and language, as well as environmental factors such as socio-economic status and early experiences

Research lead by Colombo and Lipina (2005) with children in contexts of poverty, shows that these children present low performances in CEF tasks that require self-regulation, attention, inhibition, among others, and that it is important to develop preventive interventions in this regard (Colombo y Lipina, 2005; Lipina, 2008; Lipina y Segretin, 2015)

Attention is a construct closely linked to EFs and is cross-linked to them. Attention is a complex cognitive function, organized in a hierarchical way that allows filtering, selecting and inhibiting the information that is not relevant (Portellano, 2005). This cognitive function has been divided into focused attention, sustained attention, and divided attention (Posner & Petersen, 1990).

Bonifacci and Snowling (2008) compared speed and information processing in children in different groups (typical developing, dyslexics, and borderline intellectual disability groups). The children with borderline functioning were slower and more error prone compared to the other two groups and they showed greater variability in different tasks. Alloway (2010) found greater verbal and visuo-spatial WM deficits among individuals with borderline intellectual disabilities to typical developing children age 7 to11.

By assessing CEF by means of a tablet-based test in a large sample, the present research aimed to examine the role of CEF in different clinical groups.

Purpose

The main goal of this study is to investigate the neuropsychological profile in different clinical populations through the Yellow Red and TENI assessment batteries, both in Tablet format, which evaluate different cognitive abilities related to EF and are within the paradigm of invisible evaluation through game (Rosas et al., 2015).

Methodology

Participants

Participants of the study were 175 children, (both girls and boys), between the ages of 6 and 12 years old.

They were divided in two samples, clinical sample and typical developing group (control group).

The clinical sample consisted of 135 children who have a clinical diagnosis including: Attention Deficit Disorder, Dyslexia, Dyscalculia, Borderline Intellectual Disability and Autism Spectrum Disorder.

Within the typical population, 43 children will be considered matched in age and sex with the clinical groups (Table 1).

Procedure

The participants were assessed in a quiet room by trained researchers. Testing was completed in three sessions each lasting 35 minutes.

To confirm previous diagnosis the groups were tested specially.

Table 1.
Sample Description.

Clinical Diagnosis	Frequency	Percentage
Control Group	43	24,2
TDAH	36	20,2
Dyslexia	66	38,8
Dyscalculia	16	9,0
ASD	7	3,9
Borderline Intelectual Disability	7	3,9
Total	175	100

Source: Authors.

· Dyslexia:

Reading Fluency was assessed with PROLEC R (Cuetos, Rodríguez Ruano y Arribas, 2007) or LEE (Defior & Serrano, 2006) test in Spanish.

· Dyscalculia:

WISC IV Arithmetic subtest and WRAT 3 (Wilkinson, Helman & Ross, 1993), Math Achievement Test.

ADD (Attentional Deficit Disorder) SNAP IV (Grañana et al., 2011).

ASD: ADOS (Gotham, Pickles & Lord, 2009).

· Borderline intellectual disabilities:

WISC IV (Wechsler, & Corral, 2015). (IQ: 70-79). All children were previously evaluated with WISC-IV. Parents and guardians were contacted directly and signed the informed consent.

· Core Executive Functions:

Core executive functions were measured with the tablet-based Yellow Red Test (Rosas, Espinoza y Garolera, 2020).

Yellow Red is an assessment battery made up of 4 tasks specially designed to test the core EF. These tasks are focused both on the general evaluation of EF and on the specific evaluation of its different components: CI, WM, CF and the global index of EF (Figure 1).

The reliability (internal consistency) of the Yellow Red Test was $\alpha = 0.80$ to $\alpha = 0.86$. Higher values refer to higher abilities.

*TENI (*Infant Neuropsychological Assessment Test) is an assessment tool that consists of 6 sub-tests to establish a cognitive neuropsychological profile identifying strengths and weaknesses (Tenorio, Arango, Aparicio y Rosas, 2012). The participants were tested on two tasks that focus on attention skills, specifically sustained and focused attention (Figure 1).

Statistical analysis was performed using IBM SPSS Statistics (Version 24).

Results

The significance of the Bonferroni tests (post ANOVA) of each neuropsychological profile with respect to the control group in the tasks evaluated by the YR battery are shown in the Table 2. A $p < 0.05$ was taken as a significant value. n.s. = not significant.

Table 2.
Results.

Results	TDAH	Dyslexia	Dyscalculia	ASD	BID.
Trios-CF	n.s.	n.s.	n.s	n.s.	p = 0.017
Binding WM	n.s.	n.s.	n.s.	n.s.	p = 0.022
Arrows IC	n.s.	n.s.	p < 0.001	n.s.	p < 0.001
G & P EF global	n.s.	n.s.	n.s.	p = 0.007	p = 0.002
Gobal Index	n.s.	n.s.	p < 0.001	p = 0.004	p < 0.001

Source: Author.

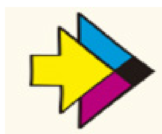
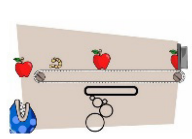
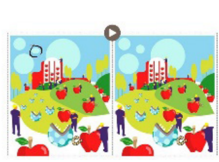
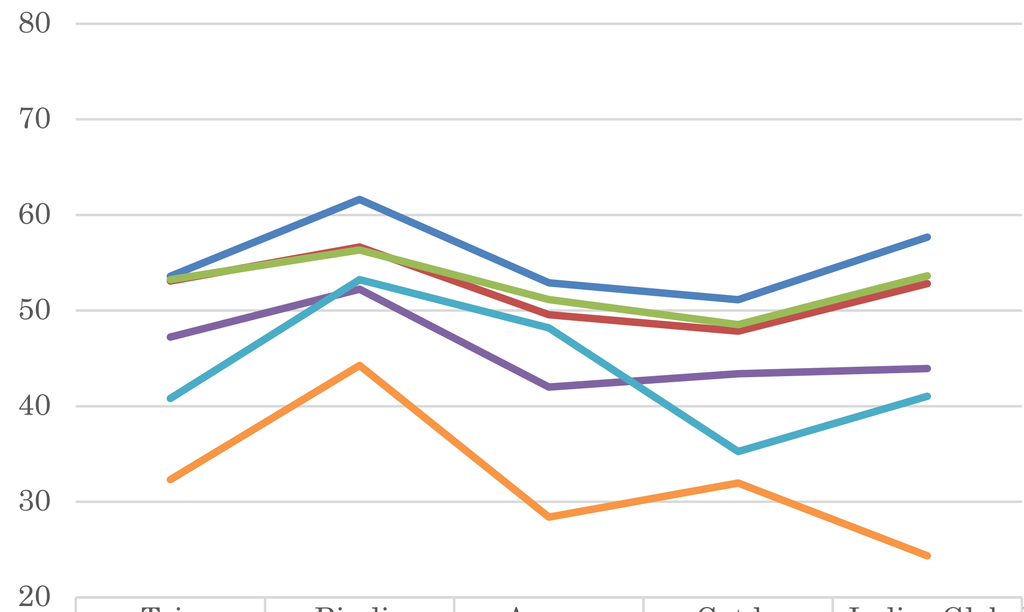
YellowRed	
Arrows 	A big arrow pointing in one of four possible directions (up, down, left and right) was presented on the top of the screen Participants were instructed to press the smaller arrow in the bottom of screen. (out of three smaller arrows) that was pointing in the same direction as the big arrow. If the big arrow were pointing down the participant was not to press any button but was to wait until the next big arrow appeared. The task included 36 items, of which 8 items were inhibition tasks. This task evaluates CI.
Binding 	Participants had to recall an increasing number of paired associations between numbers and images, which were visually presented for 5 s. To do so they had to push the correct number under the appropriate symbol or figure without a time limit. The order of the symbols/figures occasionally changed between the presentation and recall phases. The task comprised 27 items of increasing difficulty, a factor that was considered in the computation of scores. This task assesses WM.
Trios 	Participants were instructed to select three out of four figures on the basis of similarity. Four different figures (square, triangle, circle, pentagon), in four different colors (blue, red, yellow, green) and two sizes (big, small) were presented. The task included four rounds (each round having 12 items) of changing categorization principles (shape → color → size → mixed). During the task, the categorization principle changed discreetly without any information to that effect being given. For each item the participants received a visual feedback, whether the item was correct or incorrect. CF.
Cats and Dogs 	A cat or a dog was presented on the right- or left-hand side of the screen participants were instructed to press the button on the opposite side the dog appears. The task procedure was rehearsed in separate trials before the assessment proper was begun. The stimuli were presented at one second intervals. This test is a global index of executive functions as it works with both WM, IC and FC.
TENI	
Duno and the worms 	A conveyor belt appears in the screen with apples passing by. The participant has to touch the screen each time he detects apples with a worm during a period of six minutes. Sustained attention is necessary to solve this task, identifying target and not target.
Alternative Universes 	Two pictures apparently equal are showed in the screen. The participant has to identify differences. The child must point out the differences between each pair of pictures and touch them. The difficulty increases item by item. The child has to quickly identify what the difference is. It is the indicator of attention focus (AC).

Figure 1. Tasks description.
Source: Author.



	Trios	Binding	Arrows	Catdog	Indice Global
Grupo control	54	62	53	51	58
TDAH	53	57	50	48	53
Dislexia	53	56	51	49	54
Discalculia	47	52	42	43	44
TEA	41	53	48	35	41
BID ciales	32	44	28	32	24

Figure 2. Comparison between groups with clinical diagnosis and control group
Source: Author.

For the comparison of different diagnoses and the control group, the standard test scores were used (Mean 50 and Standard Deviation: 10).

In order to better compare the different groups in each task, means are taking into account according to the different subtests in the different diagnoses and in the control group.

The Figure 2 above shows the comparisons of groups diagnosed with Attention Deficit Hyperactivity Disorder (ADHD), dyslexia, dyscalculia, Autism Spectrum Disorder (ASD) and Borderline Intellectual Disability (BID). For ADHD and dyslexia, the only test that shows a notable difference comparing the CG, are the WM test and the global index. In both populations, CF has not difference to the control group. In the case of dyscalculia, all the tests are more than a half SD below the average, highlighting cognitive inhibition and the global index as the most significant measure. In the case of ASD, the two general indicators of executive functions (Cat and dogs, global index) are greatly diminished. CF is also greatly diminished, while WM is at a one DS under the control group and cognitive inhibition at a half DS. Finally, the participants with IL show a decrease of more than 1 SD in all indicators, reaching more than 3 DS low in average in the case of the global index.

Discussion

Results in this study illustrate the multidimensional nature of EF developing.

According to the results, we can determine that within each neuropsychological profile there are differences in CEF comparing with typical development group.

The Trios (FC) and Binding (Nexos) (MT) tasks only show significant differences and are affected in children with BID. The Arrow Task (IC) only in children with Dyscalculia and BID. Cats & Dogs (FE) task in the ADS and BID profiles.

Regarding the Global Index, there are significant differences in children with Dyscalculia, ASD and BID, comparing to the typical development population scores.

Regarding the Dyslexia and ADHD profiles, no significant differences were observed with respect to the typical development group in these tasks evaluated in YR, although they did provide a notable difference in the working memory task and in the global Index.

Children with ADHD obtain scores close to CG, because the tasks contained in the YR (digital format, attractive and challenging) do not require attentional support, which is what is affected in children with this profile. It remains to establish what happens with these children in the data obtained with the Infant Neuropsychological Assessment Test-TENI (Tenorio et al., 2012), in tasks that evaluate selective and sustained attention, and its correlation with the Yellow Red.

When comparing the performance in each subtest in the different groups, it can be seen that the control group is the one that obtains the best results in all the tasks and is close to the average standard score of 50.

The performances of children with dyslexia and ADHD obtain results close to the CG and the difference between groups is less than one standard deviation in all the subtests and in the global index, obtaining a remarkable difference in the WM tasks and in the global Index.

Children with dyscalculia present significantly low performance in all subtests and in the global index, with scores being observed one standard deviation below the control group.

Children with ASD obtain a significantly low score on the global index and the lowest score is observed in the Dog and Cats task, the score being two standard deviations below the control group. On the contrary, its best performance is observed in the Bindig (Figure 1) task.

Children with the lowest performance are those with Borderline Intellectual Disabilities (BID). All their scores are at least 3 standard deviations from the control group. These children belong to a low socioeconomic status unlike the rest of the evaluated children who belong to a medium / medium-high socioeconomic status and their general cognitive performance corresponds to borderline scores.

In summary, the preliminary analyzes show us that the Yellow Red battery allows us to differentiate the different diagnoses of the control group, and the global index is the one that best marks the difference between the groups. Children with dyslexia and ADHD show slightly lower scores compared to the control group in all subtests, not being statistically significant. On the contrary, the diagnoses of dyscalculia, ASD and Borderline Intellectual Disability (BID) are those that obtain scores significantly below the control group. It reveals that they present greater difficulties in the skills that integrate core executive functions: cognitive inhibition, memory of work and flexibility.

Therefore, the scores obtained made it possible to determine neuropsychological profiles within the atypical population according to each diagnosis through the Yellow Red battery assessing different cognitive abilities related to executive functions.

According with several studies where a significant predictive effect of executive functions and academic performance has been proved (Reyes et al., 2015) and the importance of executive functions in learning processes (Fonseca et al., 2016), we highlight the importance of these results confirming that the Yellow Red test is an adequate instrument to assess EF. Yellow Red is suitable to specify different neuropsychological profiles, differentiating them from the typical population, with the aim of designing and executing intervention strategies adjusted for ameliorating these difficulties. Considering that the proper development of these functions is one of many indispensable variables for school success.

The analysis of the data obtained with the TENI battery and its correlation with the Yellow Red and the WISC IV or WISV V scores in the different diagnoses is pending.

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