



# Systematic Review of Technological Methods of Evaluation of Executive Functions

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**Abstract.** Executive functions are a set of high-level skills that allow humans to consciously regulate their cognition and behavior. The main executive functions are inhibitory control, planning, working memory, cognitive flexibility, emotional regulation, among others. The use of technological resources is key to evaluate executive functions, since, in today's society; technological resources are part of the daily life of the human being and must be present in the evaluation processes of these mental abilities. In this context, this article presents a systematic review study that has sought to identify the main technological developments that are used in the evaluation of executive functions. For this study, articles published in the Scopus database were analyzed, finding 350 studies and after the inclusion and exclusion process, we worked with eight studies that developed technological devices to evaluate executive functions. The developed devices have the benefit of assessing executive functions such as inhibition, working memory, decision making, among others. Finally, it is important to mention that technological development in neuropsychological evaluation is still in its beginnings and it is necessary to work on this line of research to have more devices to achieve this goal.

**Keywords:** Executive functions · cognition · technology · neuropsychological evaluation

## 1 Introduction

Executive functions are a group of higher-order mental abilities that allow humans to consciously control their behavior and cognition [1]. These mental abilities have been described as inhibitory control, working memory, cognitive flexibility, emotional regulation, monitoring, behavioral supervision, verification, planning, initiative, organization of materials, among others [2].

The frontal lobe of the human brain has been related as the neuronal substrate that allows the work of the executive functions and when this structure is immature or affected, the human being presents a disorganization in his behavior in the different spheres in which he operates [3]. For this reason, it is of vital importance to study these mental abilities and the role in the life of the people [4].

In the field of research on executive functions, it has been reported that these mental abilities play a very important role in aspects such as academic performance, success in social relationships, organization of daily activities, participation in sports, achievement of objectives, control of emotions, fidelity and other areas. For this reason, executive functions are a topic of current interest and should be investigated from various areas, as in the case of this article, from technological context [1].

There are three techniques for assessing executive functions. First, techniques developed specifically to measure these skills, e.g. with the Stroop test, Hanoi tower, Wisconsin charts, digit retention, etc. [5]. These types of tests are classically applied in neuropsychological evaluation processes of people with brain damage or some cognitive problem [6].

A second method of evaluation of executive functions are non-specific tests, which are all the psychological evaluation instruments that have been developed to evaluate other mental or behavioral functions, however, in neuropsychology they are widely used to have a clinical criterion of how work executive functions [7].

The third type of evaluation of executive functions is deferred behavioral observation, which is based on the evaluation of these mental abilities through the report of a third person (parent, teacher, psychologist, etc.) or by a self-report of the own person involved in the evaluation process [8]. In this type of evaluation, the use of questionnaires and scales on behavior in daily life is characteristic, where executive functions play an important role [9].

This article focuses on the context of neuropsychological evaluation of executive functions, since we are interested in identifying the technological developments that have been made to evaluate them. In the next part of this article, we present a systematic review study where we have delved into the different technological devices created in the neuropsychological evaluation of executive functions.

## 2 Method

The present study was carried out using the systematic review methodology of several academic articles. This work was carried out through two procedures: (a) first, inclusion and exclusion criteria were determined for the selection of relevant data for this study; (b) second, a protocol was carried out to analyze the information from the selected articles to achieve the objective of identifying the technological devices developed to evaluate executive functions.

For the systematic review of the research found, it was necessary to comply with five stages (See Fig. 1):

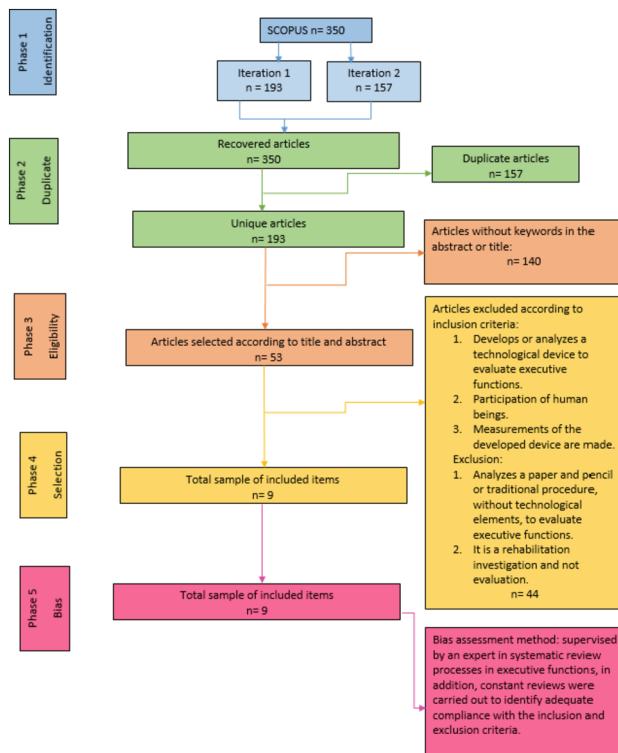
- A. Identification stage: a search of academic articles was carried out in the Scopus metabase and main journals in the context of psychology. The temporal range were works published between 2015 and 2023, using keywords in English and Spanish “executive functions, technology, assessment, psychology, frontal lobe”. Regarding language, the selected articles were in English or Spanish. Two searches were carried out using the respective keywords and filters in each metabase.
- B. Duplicate stage: duplicate articles were removed.

- C. Eligibility stage: inclusion and exclusion criteria were determined to obtain relevant data that contribute to the objective of the study.
- D. Selection stage: the articles were downloaded to be read completely and through the application of the inclusion and exclusion criteria. The articles related to the investigation were selected.
- E. Bias stage: An expert in systematic review processes in executive functions supervised the entire process; in addition, constant reviews were carried out to identify adequate compliance with the inclusion and exclusion criteria in the analysis of the articles worked on in the investigation.

## 2.1 Inclusion and Exclusion Criteria

**Inclusion:** The article develops or analyzes a technological device to evaluate executive functions. It is an article with the participation of human beings and measurements of the developed device.

**Exclusion:** The article analyzes a paper and pencil or traditional procedure, without technological elements, to evaluate executive functions. The article develops a rehabilitation investigation and not an evaluation.



**Fig. 1.** Systematic review followed in this research.

Figure 1 shows the flowchart that guided this research with the phases: 1 Identification, 2 Duplicate, 3 Eligibility, 4 Selection and 5 Bias. After the analysis process of the articles, eight papers were included which are processed in the following results section.

### 3 Results

After carrying out the analysis, eight studies [10–18] were identified with which the results were processed. Regarding the average number of participants found in the studies, an average sample size of  $M = 242.38$  ( $SD = 533.79$ ) was found. In most investigations were found a frequency between 0 and 100 participants. This data can be seen in Fig. 2.

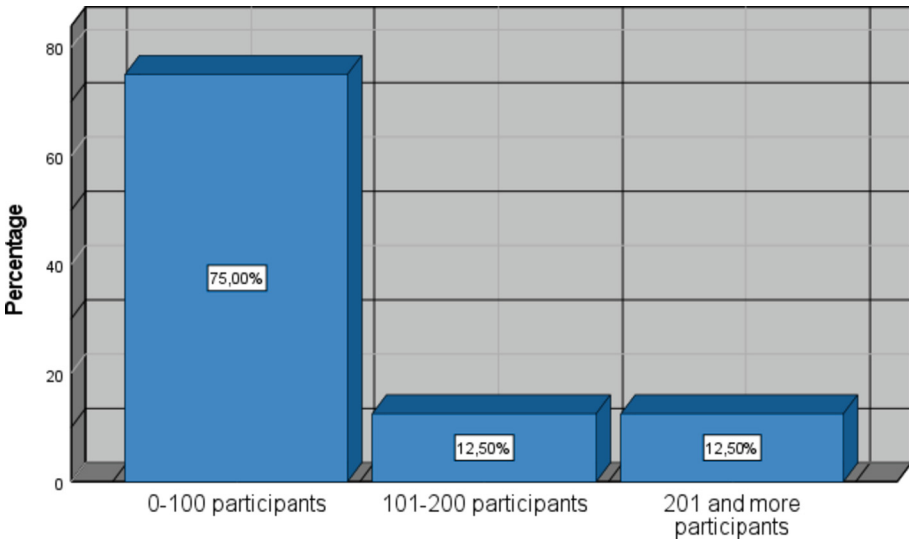


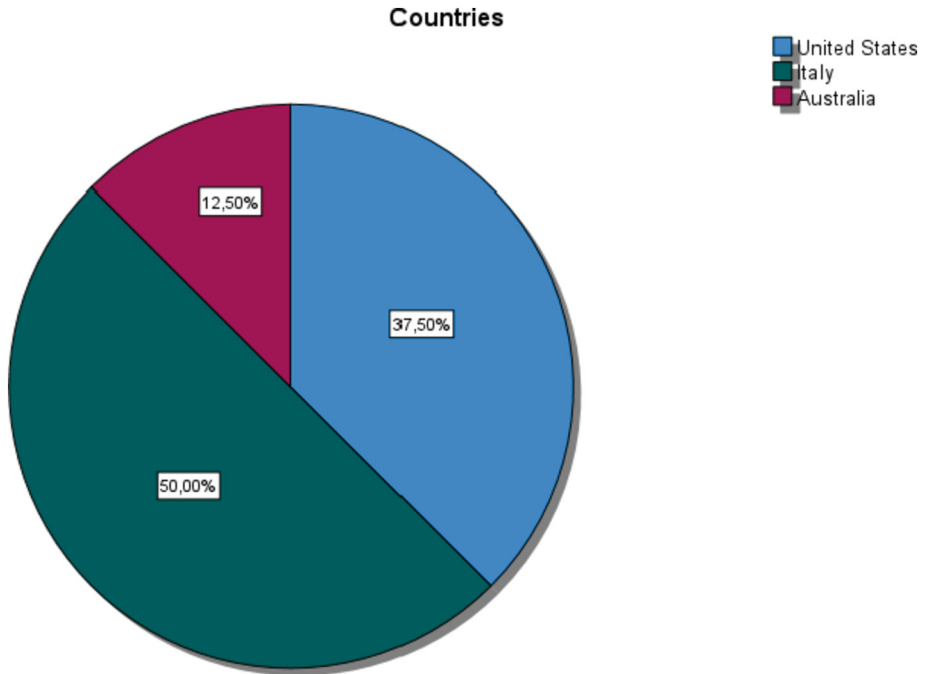
Fig. 2. Study sample size ranges.

In relation to the countries where selected investigations were carried out, it was found that Italy as the country with the highest index of technological development to evaluate executive functions. Figure 3 shows these results.

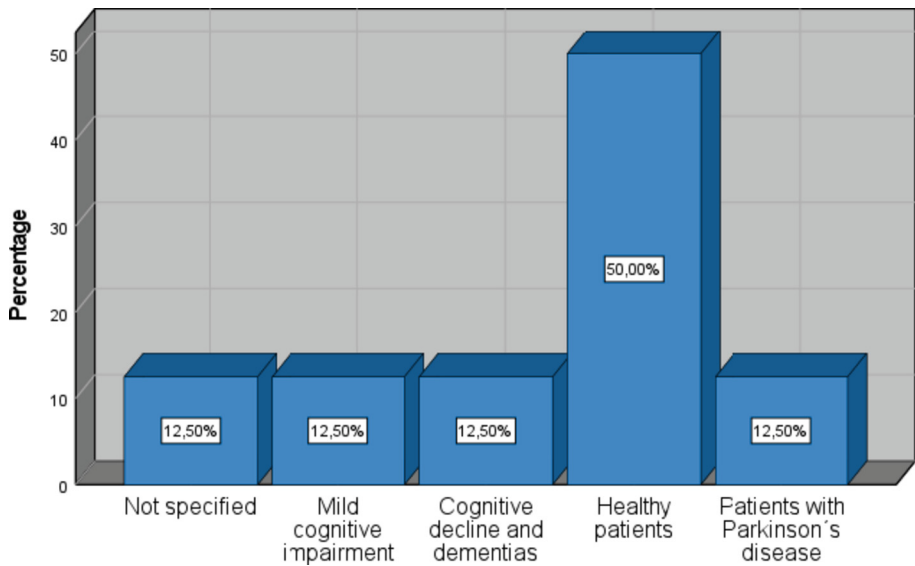
Regarding the type of population that benefits from technological developments for the evaluation of executive functions, we worked with participants with a minimum level of primary education. Figure 4 shows the characteristics of the participants.

After carrying out the analysis of the eight articles, seven technological devices developed to assess executive functions were found. These data are presented in the bar graph of Fig. 5.

Regarding the limitations of the technological developments found, it could be mentioned that in some of the devices post-evaluation processes are required, in addition to being expensive in some cases, which limits the type of population that could be evaluated.



**Fig. 3.** Countries that have generated technology to assess executive functions.



**Fig. 4.** Characteristics of the participants.

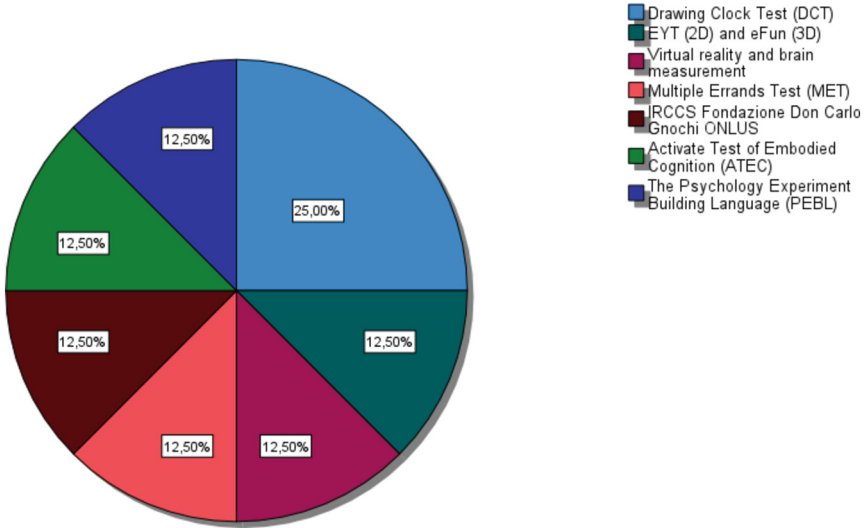


Fig. 5. Technological developments to evaluate executive functions.

On the other hand, some devices are new and the sample of their studies is small, which requires further investigation with a less biased population. Also, some instruments that use virtual reality, the resolution quality is lower compared to others available in the current market.

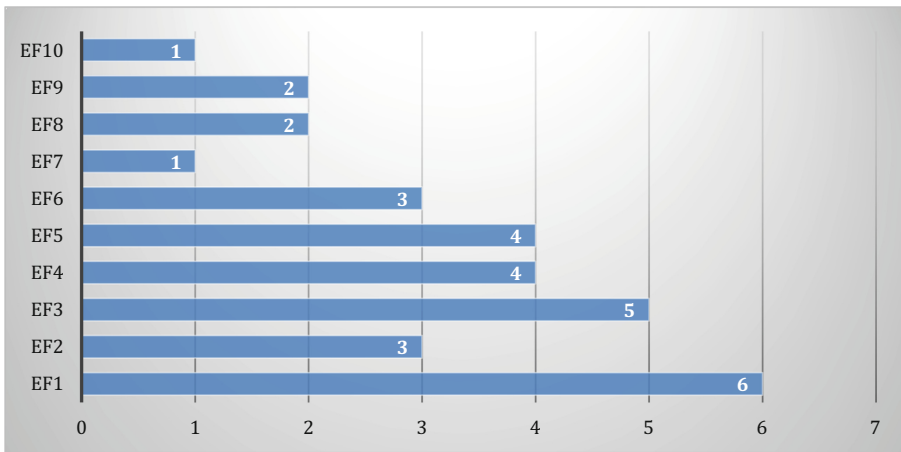


Fig. 6. Executive functions evaluated with the technological devices. **Note.** EF1: Work Memory. EF2: Verbal Fluency. EF3: Inhibition. EF4: Cognitive Flexibility. EF5: Planning. EF6: Troubleshooting. EF7: Decision Making. EF8: Attentional control. EF9: Speed of Thought. EF10: Self-regulation.

In relation to the executive functions that are evaluated in the different technological devices, it was found that working memory and inhibition are the ones that are most valued. Figure 6. Shows the executive functions evaluated.

## 4 Conclusions

In this article we have reported a systematic review investigation that aimed to identify technological devices developed to neuropsychologically assess executive functions. As a result of this review, eight articles were found that have developed technological devices to assess executive functions: Drawing clock test (DCT), EYT (2D) and eFun (3D), Virtual reality and brain measurement, Multiple Errands Test (MET), IRCCS Fondazione Don Carlo Gnocchi ONLUS, Activate Test of Embodied Cognition (ATEC) and, The Psychological Experiment Building Language (PEBL).

The main aspect of the technological developments found is the evolution that is carried out in the process of neuropsychological evaluation of executive functions, since the only way to evaluate these cognitive abilities was the use of tasks that included the use of pencil and paper, or in the best of cases, some physical object. Which can be an artificial environment for today's society that bases all its activities on technology.

Advancing in this type of evaluation is a great contribution, since today's society bases the vast majority of its activities on the use of technological devices and this reality cannot be alien to the neuropsychological evaluation process. In this way, it is achieved that people who receive the evaluation of executive functions do so with devices that are more natural to their current life and not only with obsolete techniques [18].

Regarding aspects that must be improved in the analyzed applications, the fact that the clinician must have specific training for their use is highlighted. Another aspect that should be mentioned lies in the need to have regulatory data to use the devices in the general population. It is also important to motivate a change of attitude in the mental health sciences, where more space is generated for technological development to carry out the work of evaluation or rehabilitation of patients with acquired brain damage, because many times, the proposed activities generate little interest for the patient because they are not updated.

And finally, the importance of carrying out subsequent studies where technological developments are put to the test and their convergent validity with classical neuropsychological tests is assessed. In a future study we intend to carry out a systematic review of the technological devices used in neuropsychological rehabilitation.

## Appendix

Table of selected articles

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Title	Sample	Country	Educational level	Type of population	Technological development	Limitations of the technological device	Executive functions included in the research
Dissociating Statistically Determined Normal Cognitive Abilities and Mild Cognitive Impairment Subtypes with DCTclock	123	United States	Not specified	Patients with mild cognitive defect.	DCTclock: is a test that was digitized to evaluate cognitive functions in patients with dementia.	Requires certain subsequent computer processing for use.	Working memory, verbal fluency, inhibition.
DCTclock: Clinically-Interpretable and Automated Artificial Intelligence Analysis of Drawing Behavior for Capturing Cognition	1560	United States	Not specified	Patients with cognitive impairment and dementia.	DCTclock: is a test that was digitized to evaluate cognitive functions in patients with dementia.	There are no adaptations for different population groups.	Working memory, verbal fluency, inhibition.
A Novel Approach to Measure Executive Functions in Students: An Evaluation of Two Child-Friendly Apps	81	Australia	Primary education	Elementary, first and second grade students	EYT (2D) and eFun (3D), two applications that measure executive functions, through short and easy -to-understand tasks for young people.	It is for a specific type of population.	Working memory, cognitive flexibility, inhibition.
A virtual reality tool for the assessment of the executive functions	Not specified	Italy	Not specified	Not specified	An application that integrates the electroencephalogram and a visual tracker that can evaluate to give more information about executive functions.	It takes a long time to apply, it is very expensive, it is difficult to organize and it is poorly controlled in the application conditions and with patients with	Planning, problem solving, cognitive flexibility.

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A neuro vr-based version of the multiple errands test for the assessment of executive functions: A possible approach	23	Italy	Not specified	Patients from 50 to 70 years old suffering from Parkinson's and cardiovascular accident	Multiple Errands Test (MET), evaluates executive functions through a virtual shopping (VR).	motor deficiencies. There may be unpredictable changes outside the control of the evaluator that disturb the patient at the time of evaluation	Planning, problem solving, cognitive flexibility.
A Psychometric Tool for Evaluating Executive Functions in Parkinson's Disease	27	Italy	Primary education	Patients between 18 and 90 years old and with no cognitive impairment	IRCCS Fondazione Don Carlo Gnocchi ONLUS, cuenta de tres fases importantes: (1) tareas pre-evaluación, (2) Salida 360° y (3) tareas post-evaluación.	The screen used for the 360° device is of lower quality than those available on the current market, which reduces the quality of the (VR). In addition, there is a possible misdiagnoses of Parkinson's.	Decision making, attentional control, working memory, planning and speed of thought.
The Activate Test of Embodied Cognition (ATEC): Reliability, concurrent validity and discriminant validity in a community sample of children using cognitively demanding physical tasks related to executive functioning	55	United States	Primary education	Children of a community from 5 to 11 years of age	Activate Test of Embodied Cognition (ATEC), measures executive functions through technology that captures movements.	The ATEC measurement scale is new and requires a study with a less biased population.	Working memory, coordination, inhibition, self-regulation, cognitive processing speed.
Difference Between Young and Old Adults' Performance	70	Italy	Not specified	People from 35 to 60 years of age, from rural and urban	The Psychology Experiment Building Language (PEBL) Test Battery, is a recent computerized	It is unknown whether the computerized setting	Working memory, verbal fluency, selective

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on the Psychology Experiment Building Language (PEBL) Test Battery: What Is the Role of Familiarity With Technology in Cognitive Performance ?	areas of Italy without neurologic or psychiatric diseases	software that assesses cognitive functioning	could affect later cognitive performance	attention, inhibition, planning, problem solving, cognitive flexibility.
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