A Virtual Reality tool for the Assessment of the Executive Functions

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Abstract. Background: The limitations of traditional neuropsychological tests and several difficulties in administering tests in real-life scenarios have led to the increasing use of technological tools and virtual reality (VR) for the assessment of executive functions (EF) in real-life. VR enables the development of scenarios that, reproducing daily life situations, allows an ecologically valid evaluation of EF, guaranteeing rigorous control over key variables. Several studies have adopted a multimodal approach to integrate the EF assessment through the identification of new indices and non-verbal response using different devices such as eye trackers (ET) and electroencephalograms (EEG). Objective: The main aim of this study is to propose a protocol for assessing the EFs by using an innovative technology-based task, a new app that integrates EEG and an eye-tracker. Methods: Participants are subjected to a 15/20 minute evaluation with a new technological instrument involving innovative tasks for the assessment of EFs. Each subject explores a domestic virtual scenario aiming to get out of it as fast as possible, overcoming seven different steps of increasing complexity. Through the LooxidVR device, it is possible to receive information from the eye-tracker (e.g. saccadic movements, fixations) and EEG (electrical activity of prefrontal cortex) in addition to verbal responses. Expected results: This protocol allows evaluating several EFs (e.g., planning, problem-solving) through an innovative technology-based task. Moreover, this innovative tool facilitates the acquisition of non-verbal information regarding the executive functioning of the subjects. Conclusions: This innovative app, that integrates EEG and an eye-tracker, will provide clinicians with more information about executive functioning in a short time.

Keywords: Virtual Reality, Assessment, Executive Function, Eye Tracker, Electroencephalograms

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1. Introduction

The assessment of executive functions (EFs) represents a challenge due not only to the complexity of the construct [1] but also to methodological difficulties related to their assessment [2–5]. Chan and colleagues described EFs as “an umbrella term comprising a wide range of cognitive processes and behavioural competencies which include verbal reasoning, problem-solving, planning, sequencing, the ability to sustain attention, resistance to interference, utilisation of feedback, multitasking, cognitive flexibility, and the ability to deal with the novelty" [6–8]. EFs are traditionally assessed with paper-and-pencil neuropsychological tests based on the theory, such as the Modified Wisconsin Card Sorting Test [9] or the Trail Making Test [10], which guarantee the standardized scores. However, several studies have shown that these tests are unable to reliably predict the "complexity" of executive functioning in real life settings [4,6,11,12]. Since EFs play a key role in everyday life [13] and independent functioning, it is necessary that clinical tests of EF have ecological validity [14]. An attempt to overcome this issue is the development of tests able to evaluate the different components of executive functioning in real life scenarios [3,15], such as the Multiple Errands Test, which involves performing simple tasks in a real supermarket [12]. The assessment of EF in real-life settings showed the advantage of giving a more accurate estimate of the patient's deficits than within laboratory conditions [16]. Nevertheless, such assessments also have limitations, such as long times, high economic costs, difficulty of organisation, poor controllability of experimental condition or applicability with patients with motor deficits [17]. Given these difficulties, there has been an increasing use of technological tools and virtual reality (VR) for the evaluation of FE in real-life settings. VR enables the development of scenarios that reproduce situations of daily life, allowing an ecologically valid evaluation of FE [18–21], ensuring rigorous control over key variables [18]. For example, the virtual version of the Multiple Errands Test (VMET) has been developed and successfully tested in various clinical populations, such as Parkinson's disease and Obsessive-Compulsive Disorder [22–24].

Over the years, several authors tried to further explore executive functioning through the identification of new indices and non-verbal response using different devices such as eye trackers (ET) and electroencephalograms (EEG). ET allows for tracking and recording in real-time the eye movements of subjects (e.g., saccadic and antisaccadic movements, fixations). The combination of ET and VR advantages (e.g., natural stimuli, natural movement, controlled environment and controlled data collection) makes it possible to answer many research questions in a radically innovative way. The gaze of the subject can be calculated within the 3D virtual environment and where the subject is looking during the session can be observed. Moreover, ET allows defining regions of interest in 3D space and fixation time of each region [25]. Coherently, several studies, which have adopted such multimodal approach, have showed differences between patients with compromised EF and healthy control subjects [26]. On the other hand, EEG is used to record, monitor and analyze the electrical activity and any anomalies affecting the prefrontal cortex and related associated cortico-subcortical circuits, involved in EF [27]. To date, very few studies have successfully integrated these two devices [28], and current studies have mainly focused on children [29].

2. Objective

The main aim of this work is to propose a protocol for assessing EF through an innovative technology-based task, a new app that integrates EEG and ET.

3. Methods

This protocol was designed to quickly obtain various information on executive functioning, of both healthy control subjects and neurological patients with executive dysfunction (e.g., Parkinson Disease and Mild Cognitive Impairment). This protocol provides for a complete assessment of EFs through a new VR tool that makes use of an innovative task and technological device "LooxidVR". "LooxidVR" is comfortable Mobile-powered VR headset combined with ET and EEG sensors. It records physiological signals, collecting the participants' eye (pupil size and position) and brain (6-channel, 24-bit EEG signals) data simultaneously while immersed in a virtual environment. Moreover, this technological device allows for engagement in virtual environments delivered via smartphones. These environments reproduce domestic settings, in which the participants must perform several tasks. Before starting the evaluation, the participants undergo a phase of "familiarisation" with the technological instrument. By wearing the headset, subjects are completely immersed in a neutral virtual environment that they can freely explore. This phase is designed to prevent the results from being contaminated by external causes (e.g., dizziness). Subsequently, participants are involved in a 15/20 minute evaluation with the "new technological instrument". In this phase, the subjects are immersed in different virtual experimental environments in which they must perform an innovative task for the assessment of executive functioning. The examiner encourages participants to explore the virtual environment freely. In light of the importance of evaluating EFs in real-life (ecological validity), the chosen virtual environments are common domestic environments such as the kitchen, bedroom, living room and landing.The main goal of the executive task is leave the domestic setting in the shortest possible time. To do this, the participant must plan a strategy and overcome seven different sub-tasks of increasing complexity. At each stage, the subjects must perform and successfully pass a sub-task that evaluates a particular EF. In each level, the subject is asked to answer to a sub-task, choosing between three or more "chances", according to the task's request. Several alternatives are shown to the subject, but only one of these is useful to him to continue his journey. In line with the choice of virtual environments, the sub-tasks represent situations that reproduce scenes of everyday-life that ask the subject to make different decisions accordingly. The global task is designed with the aim to tap different components of executive functioning through the seven sub-tasks (e.g. planning, decision-making, attention, problem-solving, working memory). For example, the first step aims to assess the ability of problem-solving and decision-making. The participant must explore the environment until he sees a landing with a closed door. The job is to open the door by choosing one of the three options that are provided, that is key, bottle, and screwdriver. The examiner accompanies and guides the participants along the entire path: provides the instructions of the sub-tasks, collects all verbal answers of the subjects and manages the transition from one level to another of greater complexity. If the subject chooses a wrong alternative (i.e., does not pass the level), the investigator will have to immediately stop the test. Since this instrument evaluates the actual status of executive functioning of the participants, the examiner will not be able to provide any suggestions to the subjects during the evaluation. The use of LooxidVR allows for further exploration of executive functioning; in fact, in addition to verbal responses, the examiners can obtain novel significant information from the ET (i.e., saccadic and antisaccadic movements, fixations) and EEG (electrical activity of prefrontal cortex).

4. Expected results

This innovative technology-based task allows for the quick assessment of EF through verbal response (choosing between three or more "chances"), reaction time and non-verbal data by ET and EEG.

5. Conclusion

This innovative app that integrates EEG and ET will allow clinicians to obtain integrated data about executive functioning in a short time and assess several executive abilities, such as planning, decision making, problem-solving, attention and working memory simultaneously. Moreover, it ensures executive functioning can be assessed while participants perform every-day tasks in a virtual environment that reproduces real-life context (ecological validity). Finally, this app allows testing complex cognitive functions of daily life in an enjoyable way.

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