Cognitive assessment in virtual environments: How to choose the Natural User Interfaces?

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Abstract

Facing an aging population with an increasing prevalence of dementia, the challenge lies in improving cognitive assessment and screening. Numerous paper tests are used daily as Mini Mental Status Examination (MMSE) or Montréal Cognitive Assessment (MoCA). Several assessments in virtual environments were developed to enhance ecology and appeared to be as efficient as classical tests. Using the Oculus Quest® device, a novel immersive environment was created and composed of thirteen cognitive tasks. Each scene was conceived using the navigation, selection, and manipulation 3D interaction tasks. This new environment browses several cognitive functions easily despite some technical limits.

1. Introduction

In cognitive assessment, numerous tests exist for a specific field (memory, language) or global cognition. These usual tests normally proceed in natural conditions with a patient and an examinator asking the questions orally. Most of the answers are also orally given, but some need to write, draw, or make movements. Nevertheless, these tests do not appraise the impact of cognitive impairment on daily activities, and Virtual Reality (VR) appears to be an ecological and efficient tool to detect cognitive decline throughout real situations (Parsons, 2015). Depending on the degree of immersion, the virtual environment can be classified as non–immersive, semi-immersive, or fully – immersive (García-Betances et al., 2015a). Mainly developed for video games, VR has become in a few years a new help in medical practice (Li et al., 2017) as in surgery (Schmidt et al., 2021; Winkler-Schwartz et al., 2019) or psychiatric (Freeman et al., 2017). Only five immersive environments have been previously published in cognitive assessment, as presented in the review from Clay and al in 2020 (Clay et al., 2020). In 2020, Maronnat and al (Maronnat et al., 2020) presented an immersive environment inspired from classical cognitive tests: Mini Mental Status Examination (MMSE) (Folstein et al., 1975), Montréal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) or the five words of Dubois (Dubois et al., 2002). Contrary to the other tests developed (Clay et al., 2020), this autonomous assessment browses seven cognitive domains (attention, orientation, abstraction, executive functions, visuospatial abilities, language, and memory) (Maronnat et al., 2020), which is a prominent force in the goal to perform a global evaluation. Human-computer interactions aim to reproduce natural human behaviors in virtual environments and are named Natural User Interfaces (NUI). The term "natural" means that the interface must be intuitive, easy to use, and understand (O'hara et al., 2013). The interface is not a barrier as the communication is natural and direct with the use of own senses. Either in augmented or virtual reality, several senses were exploited (Djelil et al., 2013) as touch (Marton et al., 2012; Song et al., 2008), voice (McGlashan, 1995), body movements (Hasenfratz et al., 2004), lips' movements (Jian et al., 2001), thoughts or cerebral activity (Friedman et al., 2004; Lécuyer et al., 2008) and facial expression (Busso & Narayanan, 2007). NUI can be classified according to their feasible interaction task (Bowman et al., 2005): navigation, selection, manipulation, and application control. This paper will present the immersive environment's NUI choice for each cognitive task.

2. Materials

Before using the virtual environment, choosing an adequate material to upload the environment was necessary. This material should respond to multiple characteristics selected by the authors considering that the material should be easily usable and understandable by older adults with cognitive impairment (Appendix 1) and easy to transport. Thus, they opted for the Oculus Quest (OQ)® (Appendix 2) (Oculus technologies, 2019).

3. Immersive assessment

3.1 Cognitive functions

Cognition can be summarized as the mental processes of knowledge and thinking. It comprises several functions, each participating in a global functioning (Harvey, 2019). Global cognition can be assessed throughout general tests as MMSE or MoCA. The environment (Maronnat et al., 2020) explored seven cognitive functions: Attention, memory, praxis, executive functions, language, abstraction, and orientation. PD Harvey (Harvey, 2019) has defined and classified the different cognitive domains in his state of the art. Attention is the process of attending to and sustaining relevant information while ignoring other nonrelevant information (distraction). Memory refers to information's encoding, storage, and retrieval either in the short term (working memory) or long term. Praxis corresponds to motor skills like drawing, writing, or gestural memory. Executive functions are the domain of reasoning, solving problems, or planning. Language skills are the ability to understand language, access semantic memory, identify objects with a name, and respond to verbal instructions with behavioral acts (example: "close your eyes" in MMSE). Abstraction (Jaegwon, 2017) is the cognitive process of isolating, or "abstracting," a common feature or relationship observed in several things, or the product of such an approach (example: "what is the similarity between an orange and a banana?" in MoCA). Finally, orientation is the ability to orient oneself both in time (example: "what day is it?") or space (measure: "where are we?")

3.2 3D Interactions tasks

The description of the virtual actions was made according to Bowman's classification (Bowman et al., 2005; Ouramdane et al., 2009). This classification proposes four 3D interaction tasks: navigation, selection, manipulation, and application control. This classification aims to traduce actions in the real world into virtual tasks. Navigation includes all the methods that let to know an object's position but also the ability to move inside an environment. Selection refers to the choice of an object to accomplish an action inside the environment. Close from the selection task, manipulation defines the processes leading to changes in the object's properties (position, orientation, color…). Application control corresponds to the commands which change the environment's state and properties. These commands are often included in the application's services.

3.3 Virtual scenes

The cognitive tasks are presented as independent and successive scenes. Interactions used in these scenes are presented in Appendices 4, 5, and 6. Firstly, oral questions given by the examinator were replaced by a verbal modality with instructions delivered through the headphones in every scene. Aiming to get the most realistic immersion possible, navigation was performed by the body's movements and gaze directed. In usual tests, patients use their own hands, so it was essential to making them appear in the environment as virtual hands. Oral answers were difficult to program due to technical limits, and it was decided to opt for item selections in attention, language, memory, and executive functions tasks. Manipulation movements were accomplished with the virtual hands to reproduce natural movements. For example, in the number series present in the MoCA test, it was decided to virtualize it as a list of words to remember. Firstly, the patient hears a list (square, circle, triangle) and needs to remember it. Then it will be asked to replace the figures in the correct order by moving the objects. In the abstraction task, a manipulation substituted an oral answer. For praxis evaluation, drawing and written order were also replaced by a manipulation task. Before beginning the test, was uploaded a welcome task to present the environment and a training task to test the excellent understanding of the functioning (Appendix 3). The selected NUI of these tasks are presented in Appendix 2 and correspond to those present later in the assessment.

4. Discussion

This paper presents a new virtual tool in an immersive environment to assess cognition. One of the first conditions was to provide an autonomous test without the intervention of an exterior examiner. Thus, it was necessary to find a material that led free movements and autonomous functioning, as described in part 2. OQ responded to these characteristics (Appendix 1). Moreover, OQ had already been used for cognitive training (Varela-Aldás et al., 2020) but also for cognitive assessment as for navigation memory (Ijaz et al., 2019) or visual capabilities (Foerster et al., 2016), which comforted the choice of using it. Before beginning the tasks was integrated a training scene. Thus, the user could discover the environment and try selection or manipulation tasks. Contrary to a classical leap motion, the hand's tracking in OQ is performed through two touch controllers, which let virtual hand's appearance and movements for selection and manipulation. The user needs to hold the controllers and push on buttons to accomplish these tasks. However, people with cognitive impairment might not clearly understand touch controller's functioning, and hand tracking with a leap motion might seem more accessible and more intuitive to use; the reason why we integrated a training task.

In classical assessments, patients need to write, speak, or draw and use their voices and hands. Although rapid and significant improvements occurred in VR in a few years leading to more realistic environments, several technical limits remain to reproduce natural actions. Firstly, some limitations deal with the patient oneself in the case of a sensory loss as vision or hearing impairment. Naturally, the sound level can be modulated but needs an exterior intervention. Vision's alterations as macular degeneration can also trouble results. For patients wearing glasses, OG is adapted (Appendix 1). The objective was to create an autonomous system (without an examiner). So, all the oral questions given by the examinator were replaced with vocal instructions delivered through the headphones integrated into the helmet. The choice was made for displayed answers (orientation, memory, language) that should be selected into the environment. Indeed, current advances in speech recognition are still insufficient (González Hautamäki et al., 2019; Shneiderman, 2000) to use in the system and may lead to a false or biased recognition (as an accent or a modulated pronunciation) so to an inaccurate result. Displaying written answers partially resolves the insufficiencies of speech recognition. Indeed it also has limits among people presenting a low degree of education, especially illiteracy (Franzen et al., 2020). Nevertheless, remembering displayed words also explores visual memory. For the abstraction test, oral answers were replaced by a selection and manipulation task respecting the initial evaluation where the patient must find the similarities between two objects (Nasreddine et al., 2005). When writing actions were necessary for usual assessments (clock test and drawing test), simplifications occurred in tests because patients may not understand how to use a connected pencil or manipulate a virtual one. Moreover, these scenarios would need the checking of an exterior examiner contrary to the wish for an autonomous system. So, the drawing task was transformed into a manipulation task to reproduce a scheme and the clock test into a choice task between two clocks. Withal these changes might lead to an unprecise evaluation of executive functions. In the MMSE attention task, patients must realize subtractions by steps of 7. As discussed before, transposing these operations would need speech recognition. A new task was so created with balls. In this task, the patient must select a ball always situated in the same place as the first one on the left. After the selection, the ball disappears, and the test starts again without giving the order once again. Praxis' task is close to the classical one as it uses both selection and manipulation. The patient needs to select a ball and move it to another place with a specific order (p.e yellow ball on the red plate).

5. Conclusion

Whether in immersive or non-immersive environments, VR appears to be an excellent tool to assess cognition (García-Betances et al., 2015b). The thirteen scenes browse multiple cognitive functions by using several interactions such as navigation, manipulation, or selection to reproduce as close as possible natural interactions. Some limits remain as speech recognition due to technical limitations. With continuous improvements, virtual environments and natural user interfaces will become more and more realistic, increasing immersion and ecology (Parsons, 2015). This environment remains untested among an elderly population and needs to be evaluated in natural conditions. Further studies are required to explore new human-computer interactions closer to natural actions.

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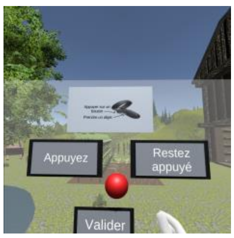
APPENDICES

Desired characteristics	**Characteristics of OQ**
Full immersion	Six degrees of freedom
Possibility of appearance of hands	Two touch controllers with four integrated cameras
Sounds compatible with hearing impairment or hearing aids	3D positional audio directly broadcasted from the headset
Compatible with glasses (vision impairment)	OLED screen 1440 × 1600 Resolution Per Eye 72 Hz Refresh Rate Supported **Glasses Compatible**
Own storage	128 GB
Free movements (no cables)	Battery included
Could be proceeded while sitting	Possible
Low weight	Less than 600 grams

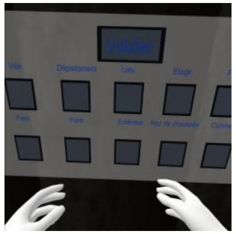
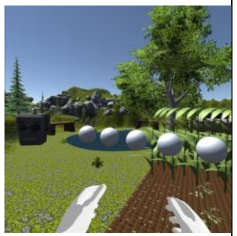
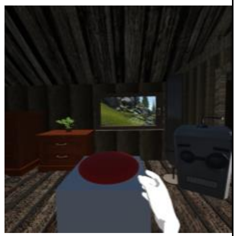
Appendix 1: Characteristics of Oculus Quest

Appendix 2: Views of Oculus Quest®

Task	3D Interaction task				View
	Navigation metaphor	Selection metaphor	Manipulation metaphor	Application control	
Welcome	Body's movements and gaze directed	Virtual hand	None	None	
Training	Body's movements and gaze directed	Virtual hand	None	None	

Appendix 3: Characteristics of welcome and training task

Appendix 4: Characteristics of cognitive tasks (1/3)

Cognitive domain		Orientation	Attention		
Task		Spatial and Temporal	Calculation	List of letters	Number series
Natural action		Oral questions	Oral answer	Oral answer	Oral answer
Virtual action		Selection of items	Selection of items	Touching a virtual button	Selection of items
3D Interaction task	Navigation	Body’ s movements and gaze directed	Body’ s movements and gaze directed	Body’ s movements and gaze directed	Body’ s movements and gaze directed
	Selection	Virtual hand	Virtual hand	Virtual hand	Virtual hand
	Manipulation	None	None	None	Virtual hand
	Application control	None	None	None	None
View		  			

<table>
<tr><th colspan="2">Cognitive domain</th><th colspan="2">Language</th><th>Praxis</th><th>Abstraction</th><th>Memory</th></tr>
<tr><td colspan="2">Task</td><td>Naming</td><td>Written order</td><td>Figure</td><td>Associations</td><td>Words with immediate and delayed recall</td></tr>
<tr><td colspan="2">Natural action</td><td>Oral answer</td><td>Writing</td><td>Drawing</td><td>Oral answer</td><td>Oral answer</td></tr>
<tr><td colspan="2">Virtual action</td><td>Selection of items</td><td>Selection and movements of items</td><td>Selection and movements of items</td><td>Selection and movements of items</td><td>Selection of items</td></tr>
<tr><td rowspan="4">3D Interaction task</td><td>Navigation</td><td>Body’ s movements and gaze directed</td><td>Body’ s movements and gaze directed</td><td>Body’ s movements and gaze directed</td><td>Body’ s movements and gaze directed</td><td>Body’ s movements and gaze directed</td></tr>
<tr><td>Selection</td><td>Virtual hand</td><td>Virtual hand</td><td>Virtual hand</td><td>Virtual hand</td><td>Virtual hand</td></tr>
<tr><td>Manipulation</td><td>None</td><td>Virtual hand</td><td>Virtual hand</td><td>Virtual hand</td><td>None</td></tr>
<tr><td>Application control</td><td>None</td><td>None</td><td>None</td><td>None</td><td>None</td></tr>
<tr><td colspan="2">View</td><td>
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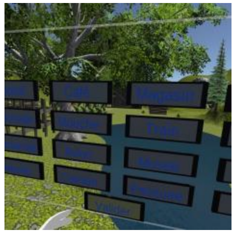
</td><td></td><td> 
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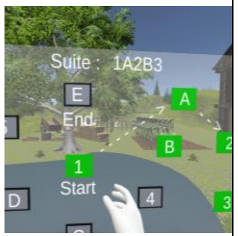
Appendix 5: Characteristics of cognitive tasks (2/3)

Cognitive domain		Executive functions	
Task		Logical Sequence	Clock
Natural action		Drawing	Drawing and writing
Virtual action		Selection of items	Selection of items
3D Interaction task	**Navigation**	Body’ s movements and gaze directed	Body’ s movements and gaze directed
	Selection	Virtual hand	Virtual hand
	Manipulation	None	None
	Application control	None	None
View			

Appendix 6: Characteristics of cognitive tasks (3/3)