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Cognitive assessment and rehabilitation in virtual reality: theoretical review and practical implications

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Virtual reality scenarios have been developed in order to assess cognitive functioning such as: memory, attention and executive function. Most scenarios replicate everyday situations like shopping activities, navigation through a park or a street, learning objects in an apartment or virtual office, or sitting and solving tasks in a classroom or apartment. Results of these studies support the use of virtual reality scenarios in neurocognitive assessment. Virtual scenarios that are used in cognitive training include a wide range of contexts from everyday life such as: a store, a kitchen, a city, as well as exercises like touching a ball on a screen for movement coordination, collecting a coconut and positioning it in a basket. Overall, virtual reality-based assessment or rehabilitation tools seem to be valid, reliable and efficient with an increased level of ecological validity.

Keywords: virtual reality, cognitive assessment, cognitive rehabilitation, memory, executive function.

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Virtual reality technology is based on an advanced human-computer interface which generates a 3D environment and uses a wide range of technologies such as: trackers and head mounted displays (HMDs) which supply the visual input, headphones and gesture-sensing gloves for acoustic input; as well as data gloves or joysticks which provide and enhance interaction. By using these devices among with appropriate software the person is immersed into a virtual environment generated by the computer (Elkind, Rubin, Rosenthal, Skoff, & Prather, 2001; Parsons, 2012).

Virtual reality technology was first used in training and assessment of aircraft pilots in a flight simulator because real-life training is dangerous, expensive, or difficult to control. Other areas of vocational training where virtual reality is used as part of vocational training are: driving, parachuting, army, fire-fighting, or Hubble Space Telescope ground control stuff (Rose, Brooks, & Rizzo, 2005; Lannen, Brown, & Powell, 2002).

Recently, virtual reality scenarios emerged as a promise tool in neuropsychological assessment (Parsons, 2012; Rose et al., 2005; Rizzo, Schultheis, Kerns, & Mateer, 2004; Schultheis, Himelstein, & Rizzo, 2002) and rehabilitation of cognitive processes (Foreman & Stirk, 2005; Man, 2010; Rose et al, 2005) and in clinical psychology as part of the desensitization process used in the treatment of different phobias such as: acrophobia, agoraphobia, claustrophobia, fear of flying and fear of public speaking (Bullinger, Roessler, & Mueller-Spahn, 2000; Kahan, Tanzer, Darvin, & Borer, 2000; North, North, & Coble, 1995; Rothbaum, Hodges, Kooper, Opdykes, Williford, & North, 1995; Vincelli, Choi, Molinari, Weiderhold, & Riva, 2000). Furthermore, virtual reality applications are expanding to clinical uses in driving assessment for persons with brain injury (Schultheis, & Mourant, 2001; Wald, Liu, & Reil, 2000), in training people with learning difficulties (Lannen, et al., 2002) or intellectual disabilities (Standen, & Brown, 2005).

Although virtual reality represents a relative new area of research and practice in the psychology field, advances in technology and computer science have supported the development of more accessible and usable virtual reality systems. As a consequence, the costs of virtual reality devices have been reduced. In addition, technical and software features of virtual reality environments are easily modified so that it allows multiple applications from which various target populations may benefit from (Elkind et al., 2001; Rizzo et al., 2006).

Main approaches in cognitive assessment

Central nervous system dysfunction results in cognitive and functional impairments. These impairments imply processes of attention, memory, language, spatial abilities, higher reasoning, functional abilities and executive function (Elkind et al., 2001; Rizzo et al., 2000). Various conditions are responsible for CNS dysfunction such as: traumatic brain injury, stroke, Alzheimer's disease, vascular dementia, Parkinson's disease, Huntington's disease, cerebral palsy, epilepsy and multiple sclerosis (Rizzo et al., 2000).

Current tools used in the assessment of cognitive functioning rely on classical paper-and-pencil psychometrics or computer-based performance tests and consist of certain amount of stimuli delivered to the subjects in a highly systematic and controlled environment. The most used classical neuropsychological tests in neuropsychology assessment of cognitive functioning are: Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993) for executive function assessment; California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 1987), Brief Visuospatial Memory Test-Revised (Benedict, 1997), and Hopkins Verbal Learning Test-Revised (Brandt & Benedict, 2001) for memory assessment; the Star Cancellation Test, a subtest in the Behavioural Inattention Test Battery (Halligan, Marshall, & Wade, 1989) for neglect assessment in cases of stroke; Stroop Color Word Interference Test and Delis-Kaplan Executive Function System (Delis, Kramer, & Kaplan, 2001) as indices of executive functioning, and impulsivity or cognitive and motor inhibition.

Nevertheless, computer-based cognitive assessment include a wide range of classical paper-based tests which were applied and delivered on computers: Automated Neuropsychological Assessment Metrics (Reeves, Kane, Winter, & Goldstone, 1995) and The Stop-it (Verbruggen, Logan, & Stevens, 2008) for executive functioning, and impulsivity or cognitive and motor inhibition; Conner's Continuous Performance Test (Conners, 2000), VIGIL Continous Performance Test (Psychological Corporation, 1996) and the Test of Variables of Attention (Greenberg & Waldman, 1993) as measures of attention.

A new paradigm in cognitive assessment which developed based on advances in computer systems is represented by virtual reality-based assessment. Although it is a relative new assessment direction, virtual reality environments for cognitive assessment were developed and offer an efficient alternative for classical or computer-based assessment. Virtual reality-based assessment include a wide ranges of cognitive processes: measures for executive function, attention and impulsivity, cognitive and motor inhibition like the Virtual Reality analog of Wisconsin Card Sorting Test (Pugnetti, Mendozzi, Barbieri, & Motta, 1998a), Look for a Match (Elkind et al., 2001), Virtual Reality Environment (Ku et al., 2003), Virtual Reality Stroop Task (Parsons, Courtney, Arizmendi, & Dawson, 2011), ClinicaVR: Apartment Stroop (Henry et al., 2011), Clinica VR: Classroom-Stroop (Henry, Joyal, & Nolin, 2012), and Virtual Classroom (Rizzo et al., 2000); followed by measures of memory such as Virtual Reality Office (Matheis, Schultheis, Tiersky, DeLuca, Millis, & Rizzo, 2007), Virtual Reality Cognitive Assessment Test (Parsons & Rizzo, 2008), Virtual reality task for incidental memory assessment (Pugnetti et al., 1998a), Virtual Reality Environment for object recognition task and object location task (Gamberini, 2000); measures of visuospatial neglect in cases of stroke like the Cancellation test developed in the Virtual reality environment (Broeren, Samuelsson, Stibrant-Sunnerhagen, Blomstrand, & Rydmark, 2007).

Paper-and-pencil neuropsychological assessment versus assessment in virtual reality

Although classical neuropsychological tests have good psychometric properties and predictive validity, they fail to tap into their results the complexity of the challenges found in everyday life. Critics of the paper-and-pencil assessment argue that most of the reactions that participants with cognitive impairments display in a classical assessment differ from those elicit in real life because classical assessment tests fail to capture the complexity of everyday life situations (Man, 2010; Parsons, 2012; Pugnetti et al., 1999; Pugnetti et al., 1998b; Rizzo et al., 2004; Rose et al., 2005; Schultheis, et al., 2002). Advocates of virtual reality assessment argue that classic paper-and-pencil tests have several limitations. First of all, they are artificial because standardized test settings require the absence of real-life stressors, complexity and distractions so that their capacity to predict real life functioning is reduced. Second, they fail to create an authentic interactivity and immersion found in everyday life which limits their application and usefulness in day to day life. Third, the assessment context in which the examiner presents a set of stimuli to the examinee and requires certain behavioral and cognitive responses orients the examinee to relevant information. This biases the examinee's responses because the focus on a specific task may compensate for other difficulties. In real life such situations do not occur, because the integrity of all cognitive processes is required in order to plan and accomplish a task. Even more, in day to day life the examiner, which tells the examinee what to do is not present and the subject has to figure out by himself what to do (Elkind et al., 2001; Rizzo et al., 2006). As a consequence, classical paper-and-pencil test have poor ecological validity because of the difficulty to see to what extent performance in classical assessment protocols relate to performance in complex and challenging day to day situations (Rizzo et al., 2004). Because of these drawbacks of paper-and-pencil tests some researchers recommend the development of other assessment instruments with powerful ecological validity (Alvarez & Emory, 2006; Elkind et al., 2001; Schultheis et al., 2002).

Virtual reality neuropsychological assessment represents an efficient alternative to classical paper-and-pencil tests which provides a high level of ecological validity. Virtual reality is based on an advanced human-computer interface and uses a wide range of technologies such as head-mounted displays- HMDs, tracking systems, headphones, gesture-sensing gloves, haptic-feedback devices, joysticks. These devices generate a 3D environment in which participants become immersed in a dynamic, natural environment generated by the computer, where scientists or clinicians control the amount and complexity of stimuli presented in order to help participants to interact with the real world (Parsons, 2012;

Rizzo et al., 2004; Rose et al., 2005; Schultheis et al., 2002). This possibility to control the range of stimulus conditions through multi-sensory experience similar to the real world enhances the ecological validity while maintaining high methodological standards through standardization of protocols (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Parsons, 2012; Schultheis et al., 2002). Furthermore, virtual reality scenarios increase participants' motivation because it allows individuals to interact in an active way rather than just to observe passively the scenario while maintaining safety from potential unsafe situations which may occur in an actual situation (Elkind et al., 2001; Matheis et al., 2007).

Virtual reality scenarios have been developed in order to assess cognitive functioning. Several studies have investigated the validity of virtual reality environments to evaluate neurocognitive abilities such as: memory (Brooks, Rose, Potter, Jayawarden, & Morling, 2004; Gamberini, 2000; Sauzéon et al., 2012; Plancher, Gyselinck, Nicolas, & Piolino, 2010; Weniger, Ruhleder, Lange, Wolf, & Irle, 2012; Weniger, Ruhleder, Wolf, Lange, & Irle, 2009) attention (Adams et al., 2009; Buxbaum, Dawson, & Linsley, 2012; Bioulac et al., 2012; Nolin, Martin, & Bouchard, 2009; Rizzo et al., 2000; Parsons, Bowerly, Buckwalter, & Rizzo, 2007) and executive function (Elkind et al., 2001; Pugnetti at al., 1998a). Results of these studies support the use of virtual reality scenarios in neurocognitive assessment because they discriminate between healthy and clinical populations and their accuracy is similar to paper-and-pencil tests. Even more results show a concordance between virtual reality measures and real world performance.

Overall, although the use of virtual reality has many advantages and empirical testing supports the virtual reality assessment paradigm, the European Federation of Neurological Societies task force recommends further investigation of the efficacy of virtual reality in neurocognitive assessment and rehabilitation (Cappa, Benkeb, Clarkec, Rossid, Stemmere, & van Heugtenf, 2005).

Computer-based neuropsychological assessment versus assessment in virtual reality

Few studies have investigated differences between virtual reality-based measures and computerized measures of cognitive processes. Advocates of virtual reality assessment question the computerized assessment tools' utility when it comes to ecological validity. Comparisons were mainly made on executive function, attention (Adams et al., 2009; Armstrong et al., 2012; Nolin et al., 2009; Parsons et al., 2007; Parsons, Courtney, & Dawson, 2013; Pollak et al., 2010) and memory measures (Gamberini, 2000). Results point out that virtual reality-based measures discriminate better than computerized-based measures between different clinical conditions and healthy participants. Nevertheless, performance on computer-based assessment correlate positively with performance on virtual reality tasks, which indicates that they measure the same constructs.

Executive function and attention assessment in virtual reality

Executive function impairments are found in brain injury, ADHD, as well as in case of schizophrenic patients. The most common used instrument for assessing executive function is the Wisconsin Card Sorting Test (WCST). Furthermore, most virtual reality measures for executive function replicate the WCST in a virtual environment

One virtual environment which replicates the WCST consists of a building in which participants have to navigate and get out of it while passing through different doors discovering the rules (Pugnetti et al., 1998a). Another virtual environment developed by Elkind et al. (2001) consists of a virtual beach. Participants have to deliver certain products (ice cream, juice, balls) by respecting some rules. Ku et al. (2003) developed a virtual system which replicates an Egyptian pyramid with rooms, corridors and doors. Participants must navigate through the pyramid choosing the doors by certain rules. Results show that the WCST analog task in virtual reality discriminates between clinical and healthy populations. Also performance on the classical WCST correlates with performance on virtual reality WCST. Nevertheless, performance obtained in virtual reality environments is lower compared to performance obtained on classical-paper-and-pencil tools, which indicates that virtual reality-based assessment triggers more cognitive resources.

Impairments in attention processes are found in clinical populations such as individuals suffering from traumatic brain injury, ADHD, or different forms of dementia (Rizzo et al., 2000). Although attention process is an important cognitive function, traditional paper-and-pencil tests consists mainly on behavioral observations techiques, measures of executive function such as Wisconsin Card Sorting Test or Stroop Interference Test, computer-delivered continuous performance tests like the Vigil Test. These measurement techniques are considered to have poor reliability and validity and low ecological validity (Rizzo et al., 2000; 2006). For instance, the Vigil Test, a form of a computer-delivered continuous performance test measures sustained vigilance, attention and impulsivity. The Vigil task is administered via a computer screen and participants are asked to respond to target items while ignoring non-target items. Usually the target items consist of letters of the alphabet which appear on the screen with various speed. The subject has to respond by clicking a mouse button whenever a certain letter, for instance, letter K appears after letter A, ignoring other succession of letters. The task is dull, repetitive demanding the examinee's attention. One limitation of this procedure is lack of ecological validity and low specificity in discriminating ADHD clinical group from healthy controls (Adams et al., 2009; Gilboa et al., 2011). The sterile environment lacks the challenges found in real life, for example in a school setting where children with ADHD go to (Gilboa et al., 2011; Rizzo et al., 2000).

Although there is evidence in favor of measures of attention in virtual reality, there is a lack of virtual environments in attention processes assessment. A search in the literature has identified two such measures: the Virtual Reality Stroop Task and the Virtual Classroom.

The Bimodal Virtual-Reality Stroop Task consists of an apartment in which participants sit in the living room and watch a TV screen through a head-mounted display (HMD). The stimuli delivered and the task is similar to the classic Stroop Effect. Results indicate that performance on the Virtual-Reality Stroop correlates with classical measures such as: the Stroop-it Task, continuous performance tests, the Elevator Counting task with distraction (Henry et al. 2012). Another virtual reality version of the Stroop Task developed in order to assess military personnel consists of a virtual environment in which subjects are immersed in a desert road in Iraq. Performance on the Virtual Stroop Task is associated with performance on the computerized and classic test of attention and executive functioning (Armstrong et al., 2013).

To our knowledge the Virtual Classroom (Rizzo, 2000) is the only virtual reality attention processes measure design to assess attention processes in children with ADHD (Adams et al., 2009; Bioulac et al., 2012; Parsons et al., 2007; Rizzo et al., 2000) or other conditions associated with impaired attention such as traumatic brain injury (Nolin et al., 2009). It consists of a virtual classroom environment in which the examinee sits in a desk in the virtual classroom. The teacher stands in front of the classroom while letters of the alphabet appear on the blackboard. The sequence of the letter and the task is similar to the computer-delivered continuous performance test measures. The letters appear on the blackboard and the subject has to respond clicking a mouse button whenever a certain letter, for instance, letter K appears after letter A, ignoring other succession of letters. Different distractors appear while the examinee responds to target items. Such distractors are: auditory (noise, a school bus arrives and makes noise, someone knocks at the classroom door) and visual (another child throws a paper airplane). These distractors are similar to real world challenges found in a typical classroom. Virtual classroom measurements include performance measures (reaction time, total correct hits, total commissions errors, total omission errors) and body movement measures (head turning, gross motor movement).

Several studies have investigated the correspondence of Virtual Classroom with computer-delivered continuous performance tests. Results show that they discriminate well between healthy and clinical population (children with ADHD) and their accuracy is superior to computer-delivered continuous performance tests because they show improved specificity compared to continuous performance tests (Adams et al., 2009; Bioulac et al., 2012; Nolin et al., 2009; Parsons et al., 2007; Rizzo et al., 2000).

Memory assessment in virtual reality

The topic of memory assessment in virtual reality is rather scarce and has focused mainly on episodic memory assessment in different clinical populations (Sauzéon et al., 2012; Plancher et al., 2010; Weniger et al., 2012; Weniger et al., 2009) or on prospective memory in stroke patients (Brooks et al., 2004). The virtual environments consist mainly of a virtual town in which participants have to drive and memorize the route or a virtual park or a virtual maze. Another virtual reality environment developed by Matheis et al. (2007) consists of a virtual office in which participants have to learn and recall different objects. Half of the participants were healthy controls while the other half was individuals with traumatic brain injury. Recall and recognition memory were tested. Results support the construct validity of the virtual office environment task in memory assessment. The task discriminated between controls and traumatic brain injury group and results correlated with classical paper-and-pencil tests. Overall, the results of these studies show that virtual reality environments could represent useful assessment tools for memory assessment. Nevertheless, some mixed results are reported by Gamberini (2000). Half of the participants were immersed and had to explore a virtual environment (apartment) and the other half were not immersed in virtual reality and had to explore the environment on a flat screen computer monitor. Results show that participants not immersed in the virtual environment had a better performance than the immersed participants. This indicates a negative effect of immersion in virtual reality on the subjects' performance.

The use of virtual reality in cognitive rehabilitation

Several studies point out the advantages of using virtual reality in cognitive rehabilitation of patients with brain injury (Foreman & Stirk, 2005; Man, 2010; Rizzo et al, 2004; Rose et al, 2005). Virtual reality training is used in rehabilitation of cognitive processes such as: attention, memory, executive function (Rizzo & Buckwalter, 1998; Rose et al, 2005). The main advantage of using virtual reality in cognitive rehabilitation is the possibility to create an authentic real life scenario with high ecological validity. This facilitates the individual's interaction with real life situations which, in turn enables the generalization and transfer of the experiences in virtual reality to everyday life situations. Nevertheless, in virtual reality a task may be repeated as many times necessary, and the amount and complexity of stimuli or the type of feedback may be controlled by the experimenter or clinician. Another advantage of the use of virtual reality in cognitive rehabilitation regards safety issues. Rehabilitation in a real life situation implies risks from both the clinician and pacient. Virtual reality allows the intervention to take place in a safe environment, but with similar characteristics to the real world. As so, the risks are diminished while the benefits are maximized (Man, 2010).

The efficacy of cognitive rehabilitation in virtual reality may be explained through the concept of environmental enrichment. Environmental enrichment is facilitated by virtual reality interventions which stimulate neuroplastic changes in the cerebral cortex. In addition, positive results of virtual reality training include improved cognitive functioning and transfer skills. Nevertheless, these findings are supported by studies using fMRI (Rose et al., 2005; Man, 2010).

Virtual scenarios that are used in cognitive training include a wide range of contexts from everyday life such as: a store (V-STORE) (Castelnuovo, Lo Priore, Liccione, & Cioffi, 2003), a kitchen (Zhang, Abreu, Seale, Masel, Christiansen, & Ottenbacher, 2003), a city (AVIRC) (da Costa & de Carvalho, 2004; da Costa, Carvalho, & de Aragon, 2000), as well as exercises like: touching a ball on a screen for movement coordination, collecting a coconut and positioning it in a basket (IREX System) (Chan, Ngai, Leung, & Wong, 2009; Kim, Chun, Kim, & Park, 2011). These results support the efficacy of rehabilitation interventions in virtual reality for the recovery of cognitive functions. Nevertheless, some authors point out that despite its' benefits, rehabilitation in virtual reality should not be seen as a panacea, because recovery is performed slowly, depending on the severity of the brain damage, with some cases where some functions do not recover (da Costa & de Carvalho, 2004; Rizzo & Buckwalter, 1998).

Despite the promising results which support the use of virtual reality interventions in cognitive rehabilitation the EFNS task force (European Federation of Neurological Societies) considers that the results are not supported by sufficient randomized controlled trials. Even more, their methodological accuracy is questionable. Some of the methodological issues identified by the task force are: the absence of a placebo group, low statistical power, reported effect sizes inadequate. As a consequence, the researchers consider that the present efficacy studies conducted in this area of research are not satisfactory (Cappa et al., 2005).

Conclusions and future directions

Because of its advantages, virtual reality environments are a promising tool in cognitive assessment and rehabilitation. Nevertheless, there is need for more studies carried out for different types of cognitive processes, conducted on different clinical population, and with different measurement instruments, not only to validate virtual reality measures, but also, to develop new procedures and interventions for a more reliable and ecological assessment and rehabilitation from which the population should benefit.

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