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The effect of learning in a virtual environment on explicit and implicit memory by applying a Process Dissociation Procedure

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Abstract

Virtual reality-based neuropsychological assessment has unique features that have the potential to increase the level of ecological validity of test results. Based on findings from the literature on the task difficulty of cognitive tasks embedded into virtual environments, we aimed to explore the task difficulty hypothesis of virtual reality in memory assessment. Our main objective was to test for differences or equivalences between performance on explicit and on implicit memory tasks in three learning environments: a computerized measure, a 3D desktop environment and a 3D virtual environment. Seventy-seven healthy participants, aged between 19 and 39 years old, enrolled in the study and were randomly assigned to the learning conditions and responded to typical virtual reality measures. Outcomes of explicit and implicit memory resulted after applying Process Dissociation Procedure. One-way ANOVA did not reveal a significant main effect of learning environment on explicit memory performance and equivalence testing showed similar performance on implicit memory across the learning conditions. In our study, both controlled and automatic memory processes were not influenced by the learning environment.

Keywords: virtual reality; neuropsychological assessment; Process Dissociation Procedure; task difficulty.

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Introduction

An increasing number of studies focused on the use of virtual reality applications in neuropsychological assessment (reviewed in Neguț, Matu, Sava, & David, 2016a; Parsons & Phillips, 2016; Parsons, Carlew, Magtoto, & Stonecipher, 2017), and on their convergent (Neguț, Matu, Sava, & David, 2015) and discriminant validity (Neguț, Matu, Sava, & David, 2016b). The increased use of virtual reality applications in neuropsychological assessment is based mainly on the assumption that virtual reality offers a more ecological assessment compared to the classical neuropsychological approach (Parsons, Carlew, et al., 2017; Parsons, Gaggioli, & Riva, 2017; Rizzo & Koenig, in press; Schulthesis & Doiron, 2017). In a broader sense, ecological validity refers to the close link between results obtained in a laboratory or controlled setting and those from real life. In neuropsychological assessment, ecological validity is the ability of a psychological test to give results like those from real life (Chaytor & Schmitter-Edgecombe, 2003; Wasserman & Bracken, 2003). The issue of ecological validity in neuropsychological assessment and the need to develop measurement instruments with an increased ecological validity have become a hot topic in the literature because current assessment tools have moderate levels of ecological validity in predicting real life performance for healthy or clinical populations (Chaytor & Schmitter-Edgecombe, 2003; Chaytor, Schmitter-Edgecombe, & Burr, 2006; Kane & Parsons, 2017; Spooner & Pachana, 2006; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2008).

Main features of virtual reality

Virtual reality usually refers to environments generated by technological devices (e.g. computers, head-mounted displays -HMDs, video capture systems, trackers, headphones, motion-sensing gloves, and/or joysticks). Some consider virtual reality as a technological system, and place less emphasis on the human experience (Steuer, 1995). In the case of neuropsychological assessment that uses virtual reality to test cognitive functions (e. g. memory, executive functions, attention and visuospatial analysis), the term virtual reality usually defines a virtual environment that contains cognitive tasks. The cognitive tasks from classical tests are embedded in virtual scenarios generated by computer and technical devices (Bohil, Alicea, & Biocca, 2011; Rand, Katz, & Weiss, 2007; Rizzo & Koenig, in press). The participant is immersed in the virtual world and has a 360° “first person” view of the environment in which he has to perform the cognitive tasks. The virtual scenario may replicate real world environments such as virtual cities (Lecouvey et al., 2017; Montenegro & Argyriou, 2017; Plancher, Tirard, Gyselinck, Nicolas, & Piolino, 2012), shopping environments (Parsons & McMahan, 2017; Rand et al., 2007), virtual classrooms (Iriarte et al., 2016; Rizzo et al., 2006), offices and virtual apartments (Brooks, Attree, Rose, Clifford, & Leadbetter, 1999; Matheis et al., 2007; Parsons & Carlew, 2016; Saidel-Goley, Albiero, & Flannery, 2012; Sauzéon et al., 2016). Such virtual environments are designed to measure cognitive process like: attention and executive functions (Armstrong et al., 2013; Erez, Weiss, Kizony, & Rand, 2013; Iriarte et al., 2016; Parsons & Carlew, 2016; Rizzo et al., 2006), memory (Brooks et al., 1999; Gamberini, 2000; Lecouvey et al., 2017; Lo Priore, Castelnuovo, Liccione, & Liccione, 2003; Mania & Chalmers, 2001; Parsons & McMahan, 2017; Plancher & Piolino, 2017) and visuospatial analysis (Broeren, Samuelsson, Stibrant-Sunnerhagen, Blomstrand, & Rydmark, 2007; Kim et al., 2004) among samples of healthy controls and among a wide range of clinical conditions (for a review see Neguţ et al., 2016a; Neguț et al., 2016b; Parsons & Phillips, 2016). Some scenarios contain environmental distractors, like moving objects or noise that increase the similarity between the virtual and real environment (Areces, Rodríguez, García, Cueli, & González-Castro, 2016; Erez et al., 2013; Iriarte et al., 2016; Neguț, Jurma, & David, 2017; Parsons & Carlew, 2016). Because it is close to the real world, the virtual reality-based neuropsychological assessment has the potential to assess what the client might do/ does in the real world and to predict real life performance (Kane & Parsons, 2017; Parsey & Schmitter-Edgecombe, 2013; Rizzo & Koenig, in press; Rose, Brooks, & Rizzo, 2005). Another variable that impacts episodic memory performance in virtual environments is the type of navigation: passive and active navigation. Usually in passive exploration conditions participants do not explore freely the environment and are either guided by the experimenter (e.g. in a virtual apartment exploration or a virtual town, see Plancher et al., 2012; Sauzeon et al., 2011) or sit in a fixed position (e.g. a virtual classroom or virtual apartment, see Iriarte et al., 2016; Parsons & Carlew, 2016; Rizzo et al., 2006). In active exploration conditions participants are free to move in the virtual environment and explore it on their own using devices such as joysticks or steering wheels and pedals in virtual towns (Plancher et al., 2012; Sauzeon et al., 2011). It seems that active navigation enhances episodic memory performance, but only on item-specific measures, and not on relational measures (for a review see Plancher & Piolino, 2017) because it strengthens distinctive memory traces and enriches sources of memory. From this direction, it might be the case that virtual reality might actually help improve memory performance.

Previous research indicates that virtual reality tests have discriminant validity, as they can successfully discriminate between healthy controls and clinical populations (for a review see

Neguț et al., 2016b) and have convergent validity with traditional measures with medium magnitude of the relationship (for a review see Neguţ, Matu, Sava, & David, 2015). For memory, results are similar (Neguţ et al., 2015; Neguț et al., 2016b). For example, studies on episodic and prospective memory show that virtual reality-based measures are valid (for a review see Plancher & Piolino, 2017). Among a sample of younger and older adults, older adults performed worse on prospective memory tasks in a virtual town as they recalled fewer intentions (Lecouvey et al., 2017). In a virtual environment grocery store, older adults remembered fewer items in a free or cued recall test, had fewer items in the shopping cart and were less likely to remember other instructions (Parsons & Barnett, 2017). Sauzéon et al. (2016) identified differences in episodic memory in a virtual apartment between patients with Alzheimer disease, healthy older adults and younger adults. In plus, the virtual reality test discriminates well between the categories of participants and replicates their memory profile. Another recent study that compared every day memory performance of patients with Alzheimer disease with healthy younger controls points out that healthy participants outperformed the clinical sample on recall and recognition tasks in a virtual doctor's office and living room (Montenegro & Argyriou, 2017). According to Picard, Abram, Orriols, & Piolino (2017) a virtual town designed to measure episodic memory can successfully assess episodic memory development among children and adolescents.

An important topic that relates to the ecological validity of virtual reality-based measures is the level of difficulty of cognitive tasks embedded in virtual reality (Neguţ et al., 2016a). Studies that compared the performance of traditional paper and pencil or computerized measures with virtual reality measures in terms of their difficulty (see Neguţ et al., 2016a for a meta-analysis) show that, overall, tests in virtual reality are more difficult, as participants performed worse on them. Some argue that because the virtual environments closely replicate the real world they are likely to be more cognitive demanding compared to the classical tests. The cognitive system must process additional information and stimuli to solve a task (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Elkind, Rubin, Rosenthal, Skoff, & Prather, 2001; Gamberini, 2000; Lo Priore et al., 2003). According to Neguţ et al. (2016a) tasks embeded in virtual reality are more difficult. Thus, further analysis shows poorer performance and increased tasks difficulty in virtual reality for executive function and visuospatial analysis measures, but better performance and reduced task difficulty for memory measures. Few studies that focused on memory processes in virtual reality aimed to explore their level of difficulty by comparing directly the performance on virtual reality tests with analogue traditional tests. For example, Gamberini (2000) compared the performance in object recognition and object location tasks and found significant differences only for the object recognition task with better performance on the computerized task. Lo Priore et al. (2003) found nonsignificant differences between virtual reality and computerized performance. Mania and Chalmers (2001) reported mixed results in the performance on virtual reality tests and computerized tests across states of memory awareness. No significant differences emerged on the memory performance in the remember state, but the performance was better in virtual reality in the guess state of memory awareness condition Also, no significant differences were reported for spatial memory.

Applying a Process Dissociation Procedure in virtual reality

The topic of conscious or controlled processes and unconscious or automatic process of memory has been widely debated in the literature over the past decades (Butler & Berry, 2001; Gruppuso, Lindsay, & Kelley, 1997; Jacoby, 1991; Koen & Yonelinas, 2016; Roediger, 1990; Rosenstreich & Goshen-Gottstein, 2015; Timmermans & Cleeremans, 2015; Toth & Parks, 2006; Yonelinas, 2002). Implicit and explicit memory corresponds to the level of consciousness or awareness shown by a subject in recall and recognition tasks. Explicit memory refers to intentional or conscious retrieval of information. Implicit memory targets any change in performance that is produced by prior experience and without intentional or conscious awareness of this influence in the retrieval process (Rosenstreich & Goshen-Gottstein, 2015; Schacter, 1992; Timmermans & Cleeremans, 2015; Yonelinas, 2002). The interest in implicit memory has begun with the development of implicit or indirect measures of memory (Koen & Yonelinas, 2016; Toth, Reingold, & Jacoby, 1994). Implicit tests of memory measure unconscious influences of memory because the retrieval strategy (recall, recognition) is both unintentional and unconscious (Butler & Berry, 2001; Koen & Yonelinas, 2016; Rosenstreich & Goshen-Gottstein, 2015; Toth, Lindsay, & Jacoby, 1992; Toth et al., 1994). Measures used in the study of implicit memory reflect indirectly memory performance. They consist mostly of a word stem completion or fragment completion tasks, word cued association, and perceptual identification (Butler & Berry, 2001; Jacoby, Toth, & Yonelinas, 1993; Koen & Yonelinas, 2016; Yonelinas, 2002). One of the most used measures is the word stem completion task. In the study phase participants are exposed to a list of words and in the test phase they are asked to generate a response by completing the stem with the first word that comes to mind. Automatic influences of memory are observed by the tendency to complete the stems with words studied in the study phase (Jacoby et al., 1993; Koen & Yonelinas, 2016; Yonelinas, 2002). Explicit measures of memory are equivalent to classical tasks of recall and recognition. On explicit tests performance is measured by an intentional retrieval strategy and requires participants to consciously remember the study material (Koen & Yonelinas, 2016; Meiran & Jelicic, 1995; Toth et al., 1992; Yonelinas, 2002).

The Process Dissociation Procedure (Jacoby, 1991; Jacoby et al., 1993) focuses on the process rather than on the tasks (direct or indirect tests of memory). The procedure overcomes the contamination problem, i.e. the probability that conscious memory could contaminate the results on implicit tests or vice versa, by placing the automatic and controlled influences in opposition within a single memory task rather than measuring these influences within different tasks (Jacoby, 1991; Jacoby et al., 1993). This is achieved by creating an inclusion and exclusion test condition and then by computing estimates of conscious recollection and unconscious or automatic influences using simple mathematic formulas.

The procedure contains two main phases: a study phase and a test phase. In the study phase participants have to learn a list of words. In the test phase, they have to use stems as cues to recall studied words. The test phase has two conditions: inclusion and exclusion. In the inclusion condition participants have to recall old words using the stem as a cue. They are instructed to complete the stem with an old word and if they cannot do so they should complete the stem with the first word that comes to mind. The inclusion test is identical to a classical cued recall test were participants have to recall the studied words and, if not able they just have to guess the words. In the exclusion test condition participants also have to complete the stem by generating new words. This time they are instructed to complete the stem with other words than those studied in the study phase. They are explicitly told to exclude the old words and to complete the stems with new words. If they fail, they should complete the stems with the first world that comes to mind. After computing the probability to complete the stems with correct words in the inclusion test and the probability to complete the stems with studied, old words in the exclusion test, results are combined to provide separate estimates of conscious recollection and unconscious or automatic influences using the formula R + A(1-R).

In the inclusion test condition, the participants can respond with a studied word if they can consciously recollect it with a probability of R or if they fail to do so and the word comes automatically to their mind with a probability of A. Thus, there are two probabilities. The first probability is to recollect the studied words (R). Second, the probability that the word comes automatically to mind (A) because recollection failed (1-R).

Next, in the exclusion test condition, the participants can complete the stems with studied words only if the words come automatically to mind (A) without conscious recollection, as they failed to consciously recollect (R) they were presented in the study phase A(1-R).

Finally, the recollection (R) is computed by subtracting the probability of completion on the exclusion test condition with old words from the probability of completion on the inclusion test condition with either studied words or studied words that come automatically to mind without conscious recollection: R = Inclusion-Exclusion. By dividing the probability to complete the stems in the exclusion condition with old, studied words by 1-R a measure of automatic or unconscious influences can be estimated: A=Exclusion/(1-R) (Jacoby, 1991, 1996; Jacoby et al., 1993).

Overview of the current research

To our knowledge no study by now has explored the explicit and implicit memory paradigm in a virtual environment. The distinction between the two memory processes has gained attention not only for theoretical consideration, but also for possible practical implications. In neuropsychology, the difference between implicit and explicit memory is seen in amnestic patients who perform worse on tasks that ask them to report past experiences compared to the situation in which they have to perform a task using past experience (Jacoby, 1991). The amnesic patients' performance on implicit memory tests shows that implicit memory is preserved, while explicit memory is less impaired (Baddeley & Wilson, 1994; Graf & Schacter, 1985). Similar results were obtained in a population with brain damage (Ste-Marie, Jennings, & Finlayson, 1996). In the case of older adults compared to younger adults, a meta-analysis points out stronger unconscious influences and weaker conscious influences (Rybash & Hoyer, 1996). Taken together, these results highlight the importance of dual memory process -implicit and explicit- in neuropsychological assessment, and rehabilitation.

Recently, the Process Dissociation procedure was used among various samples of clinical populations such as autism (Ring, Gaigg, & Bowler, 2015), schizophrenia (Guillaume, Thomas, Faget, Richieri, & Lançon, 2015), Parkinson disease (Pitarque et al., 2017), Alzheimer disease (Kessels, Feijen, & Postma, 2005), as well as in healthy ageing (Koen & Yonelinas, 2016). In a computerized task, healthy controls and participants with autism had to study pictures of rooms and the location of objects and then to perform an object location and object recognition task. Results showed that participants with autism had explicit memory difficulties as they could not retrieve the objects' locations, but could remember them unconsciously, as implicit memory performance was unaffected. Among a sample of participants with schizophrenia that had to remember pictures of daily-use objects, the performance was better in the inclusion task, but implicit and explicit memory process were both impaired (Guillaume et al., 2015). In a study with Parkinson disease participants that had to learn pictures, Pitarque et al. (2017) pointed out that implicit memory is preserved, while explicit memory is impaired. Similar results were obtained in a sample of healthy older adults that had to remember both words that were read aloud and written words that appeared one computer desktop (Koen & Yonelinas, 2016). Such results bring support in favor of the validity of Process Dissociation Procedure across various population samples, learning conditions and stimuli format and presentation (e.g. auditory, written, picture, word).

In the current study, we aimed to explore the issue of task difficulty in implicit and explicit memory in a virtual reality apartment. Briefly, we investigated explicit and implicit memory performance in three distinct learning environments: a computerized environment, a 3D desktop environment and 3D virtual environment. The computerized environment corresponded to a classical assessment setting and the stimuli were delivered on a desktop screen. The 3D desktop environment was based on a virtual apartment with objects delivered on a desktop screen. The 3D virtual environment was based on the same apartment environment as the 3D desktop condition and was delivered via a CAVE automatic virtual environment. The computerized environment had a low level of immersion, the 3D desktop environment was also non-immersive, while the 3D virtual environment was immersive (Parsons, Carlew, et al., 2017; Rizzo & Koenig, in press). Previous research suggested that explicit memory is usually more costly than implicit memory, as indicated by differential effects of divided attention on a retention task (Spataro, Cestari, & Rossi-Arnaud, 2011) and by practical observations of amnestic patients' implicit and explicit memory performance (Baddeley & Wilson, 1994; Graf & Schacter, 1985). Because explicit memory is a slow, controlled process that requires a high amount of cognitive resources (Payne, 2008) we expected that the type of learning environment will impact the explicit memory performance. On the other hand, because implicit memory is an automatic process, that occurs quickly and with minimal cognitive effort and maximum efficiency (Payne, 2008), we expected a pattern in which the implicit memory remained unaffected by the type of learning environment. We used the Process Dissociation Procedure

(Jacoby, 1991, Jacoby et al., 1993) framework to obtain measures of explicit and implicit memory.

Finally, we first predicted that explicit memory would be affected by the type of learning environment. Thus, because studies that tested the impact of virtual reality in memory assessment revealed mixed results (Gamberini, 2000; Lo Priore et al., 2003; Mania & Chalmers, 2001; Neguţ et al., 2016a) we did not predict which learning environment would impact the most the explicit memory performance. Second, we anticipated that implicit memory would not be affected by the type of learning environment.

Method

Participants and experimental design

Seventy-seven healthy participants, aged between 19 and 39 years old (*M* = 23.96, *SD* = 4.07), participated in the study. Most of them (N=45, 71.4%) were females and psychology students who received extra credit for their participation in the study (see Table 1).

Insert Table 1 about here

We used a between-subject one-factorial experimental design with three experimental conditions that correspond to three learning environments: a computerized learning environment, a 3D desktop environment and 3D virtual environment. Participants were randomly assigned to one of the experimental conditions.

Measures

Sociodemographic variables. Participants' age and gender were reported.

Trail Making Test Part A and B, paper-and-pencil version (TMT, Reitan, 1958) was used as an executive function measure. Part A ask participants to draw lines as fast as possible in order to connect in ascending order 25 numbers encircled on a page. Part B is considered more difficult because participants connect encircled numbers and letters alternating between numbers and letters. The task requires connecting the numbers in ascending order and the letters in alphabetic order. The total time spent to complete each form is measured. Lower scores represent better performance.

Cybersickness was assessed with the Simulator Sickness Questionnaire (SSQ, Kennedy, Lane, Berbaum, & Lilienthal, 1993). It consists of 16 items that measure motion symptoms caused by immersion into the virtual environment. Participants rate on a scale of 0-3 the intensity of symptoms related to exposure in the virtual reality (e.g. general discomfort, blurred vision, dizziness with eyes open, nausea). The presence of at least one severe symptom indicates cybersickness. Internal consistency was excellent (Cronbach's $\alpha = .91$).

Explicit and implicit memory measures were estimated using Process Dissociation Procedure (Jacoby, 1991; Jacoby et al., 1993). By applying an inclusion and exclusion test condition, estimates of recollection and automatic or unconscious influences were computed.

The terms recollection and explicit memory, as well as automatic, unconscious influences and implicit memory are used interchangeable in the present paper.

Materials

Apparatus and software

For each of the three experimental conditions we had three learning environments. The first environment corresponded to a classical learning context as the stimuli were delivered on a computer screen. For this we used HP Z800 Workstation with a resolution of the display at 1440 × 900 at a refresh rate of 60 Hz. The stimuli were programmed using OpenSesame 2.9.4 Software (2015). For the second environment, we used the same workstation. The virtual environment was presented on the computer desktop with a 3D view. The virtual scenario consisted of a standard apartment scenario developed by EON Reality, Inc. (http://www2.eonexperience.com/eon-models/main.aspx). The original virtual apartment ran on EON Viewer 7.6.0.4840 software. The virtual apartment was modified according to the research objectives and items/objects were added using EON7 Software Suite, EON Studio 7.6.0.4840 (2010). The objects had .3Ds or. CAD format. The virtual environment ran on a CAVE Automatic Virtual Environment with four walls. The EON Icube is produced by EON Reality, Inc. (http://www2.eonexperience.com/eon-models/main.aspx) with following technical specifications: 4 walls constructed of acryl screens, 4 projectors with a resolution of the display at 1400 × 1050 pixels at a refresh rate of 96 Hz with 3000 ANSI Lumens luminosity, stereoscopic 3D active shutter glasses, a NaturalPoint tracking system with 12 tracking cameras, a 360 Microsoft wireless controller for Windows, and a Surround Sound System 500W.

Virtual and computerized environment

The virtual apartment used in the 3D desktop condition and in the full immersive 3D conditions were the same. The single difference between them was the level of immersion. Virtual environments delivered on a desktop screen are considered non-immersive, while the CAVE environments are the most immersive environments available today (Parsons, Gaggioli, et al., 2017; Rizzo & Koenig, in press). The virtual apartment had 3 rooms: a bedroom, an open space living room with a kitchen and a bathroom with objects that are usually found in an apartment (e.g. bed, chair, table, glasses, bookshelf, vase, and flower) (see Appendix 1). The computerized environment had images of the same objects within the virtual apartment (e.g. bed, chair, table, glasses, bookshelf, vase, and flower) (see Appendix 1). The objects were randomly displayed on the computer desktop screen. All the stimuli were carefully selected after reviewing papers that used virtual environments (apartments and offices) to assess memory processes (Brooks et al., 1999; Matheis et al., 2007; Sauzéon et al., 2016).

Study and test phase

The experiment consisted of a study phase and a test phase.

In the study phase, we manipulated the type of learning environment. The computerized and virtual environment contained identical stimuli. Forty objects were used. Thirty-six objects were the critical stimulus. Four objects found in the bedroom and bathroom were chosen to control for primacy and recency effects and were not used to compute implicit and explicit memory score. They were buffer items to accommodate participants to the procedure.

The study phase lasted 300 seconds for each environment. In the virtual apartment participants spent 75 seconds in each room, as there were 4 rooms (bedroom, open space living room with kitchen and bathroom). In the computerized condition participants viewed objects for

300 seconds with an interstimulus interval of 6.8 seconds. The learning phase started each time with objects from the bedroom, and continued with objects from the open space livingroom and kitchen that were randomized. It always ended with objects from the bathroom. Thus, we could not control the equivalence of stimulus order or time spent for each item in the virtual apartment. To increase experimental control, we chose a predefined route for navigation in the environment and set an identical amount of time per learning trial, but could not account for the order in which participants chose to look or for the time they allocate for each item. Similar procedures are used by studies that use virtual apartments to assess episodic memory (Brooks et al., 1999; Saidel-Goley et al., 2012; Sauzéon et al., 2016). Although one could assume that this diminishment in control threatens the internal validity, the procedure is similar to real world situations in which participants perform a learning task. Consequently, the level of ecological validity is increased (Parsons, Carlew, et al., 2017; Parsons, Gaggioli, et al., 2017; Rizzo & Koenig, in press; Schulthesis & Doiron, 2017).

For the test phase 76 word stems were generated. Each stem contained different letters. and begun with two different letters. Forty stems corresponded to words that represent objects presented in the study phase, while 36 stems did not correspond to objects presented earlier. Word stems were created using the first two letters of a word followed by a long dash (fl___). The words had different number of syllabus and letters. The participants were not restricted to complete the stem with a particular number of letters or syllabus.

The study phase and test phase begun and ended with 2 buffer stems which served for multiple purposes. The stems were programmed and displayed on desktop screen using OpenSesame 2.9.4 Software (2015).

Procedure

The procedure was approved by the University Research Ethics committee. Written consent from the participants was obtained prior to the experiment. After signing the written consent, the experiment begun. Participants were randomly assigned to one of the three experimental conditions in the study phase. The experiment had two main phases: study and test phase.

In the study phase, the participants from the 3D desktop or 3D virtual reality condition were told that they will be guided through a virtual apartment by the experimenter. The passive exploration of the apartment was chosen to control for possible biases caused by individual differences in navigation, time spent in each room, and abilities in mastering the joystick. In the virtual apartment, they were told that they wiuld see objects that are usually found in an apartment. As they navigated in the apartment they were told they would have to learn as many objects as possible. The participants in the full immersive virtual reality condition were instructed to put on the stereoscopic 3D active shutter glasses and if during the exploration they felt dizzy to remove the glasses. The same predefined route was used for each participant. The exploration begun with the bedroom, continued with the open space living room and finished with the bathroom.

The participants from the computerized condition received the same task instructions. They were told that on the desktop screen they would see objects that are usually found in an apartment. They had to learn as many as possible. The objects appeared in the center of the screen at constant speed and in random order, except for two objects (bedroom and bathroom) at the beginning and end of the trial.

Immediately after the study phase, the test phase began.

In the test phase, the stems were in Calibri font, lowercase letters with a font of 72 that appeared in the center of a desktop white screen with a constant speed of 10 seconds per each stem. After the 10 seconds, the next stem appeared on the screen even if no response was given by the participant. The presentation order of each stem was randomized for each participant except for the first and last two stems that were buffer items. Half of the stems were assigned to the inclusion condition while the other half were distributed to the exclusion condition. However, the order of appearance was counterbalanced. More specific we created two list-conditions so that every stem had equally the chance to be part of an inclusion test or exclusion. Order of presentation was counterbalanced between subjects and each participant was randomly assigned two one of the condition-lists.

In the inclusion test condition when the stem was displayed, the word “old” also appeared in the upper left side of the screen. The participants were then instructed to try and complete the stem with an old word or to try and use the stem to recall a studied word. If they could not remember any word they should complete the stem with the first word that comes to mind. In the exclusion test condition, along with the stem the word “new” appeared. In this case the participants had to complete the stems with any words except those studied in the study phase. They should avoid completing the stems with words they have learned before. However, if they find difficult to distinguish between the old words they should complete the stem with the first word that comes to their mind. This procedure was adapted using Jacoby’s Process Dissociation Procedure (Jacoby, 1991; Jacoby et al, 1993). The participants’ responses were recorded on a blank sheet of paper by the experimenter.

The testing session lasted for approximately three-quarter hour. The primary dependent variables were explicit and implicit memory performance as measured by the Process

Dissociation Procedure (Jacoby, 1991; Jacoby et al, 1993), whereas secondary dependent variables resulted from scales typically used in virtual reality research and in neuropsychological assessment. Simulator sickness was used to account for cybersickness and was administered immediately after the test phase. Trail Making Test was also administered to account for potential individual differences in executive function. Previous research has shown that executive functioning mediates the learning of 3D material (Korthauer, Nowak, Frahmand, & Driscoll, 2017; Sauzéon et al., 2016).

Statistical methods

Like Jacoby et al. (1993) who consider implicit and explicit memory as independent processes, we performed two distinct statistical analyses for each of the memory process.

For explicit memory, we predicted different performance between the three learning conditions and performed an Analysis of Variance (ANOVA) with type of learning environment (a computerized measure, a 3D desktop environment and 3D virtual environment) as between factors. Four participants had a negative value for estimates of recollection which indicates a measurement error. To account for that, we assigned a 0 value as suggested by (Gruppuso et al., 1997).

In the case of the implicit memory, we expected a similar performance across the three different learning environments. Therefore, we performed an equivalency testing procedure. In equivalence testing one aims to see whether the groups under study have equivalent means or if the differences across experimental conditions are trivial (Cribbie, Arpin-Cribbie, & Gruman, 2010; Walker & Nowacki, 2010; Wellek, 2010). While in the case of traditional difference testing, one aims to reject the null hypothesis that states that there is no significant difference between experimental conditions, in equivalence testing the null hypothesis to be rejected is that the interventions/treatments are not equivalent. On the other side, the research hypothesis in traditional testing considers differences between interventions/treatments, while in equivalence testing the research hypothesis treats the interventions/treatments as equivalent. Therefore, the statistical procedure in case of equivalence testing is different than the one used in traditional testing (Cribbie et al., 2010; Walker & Nowacki; 2010; Wellek, 2010). After reviewing the literature (Piaggio, Elbourne, Pocock, Evans, & Altman, 2012; Walker & Nowacki, 2010; Wellek, 2010), we have set an equivalence margin of 20% that would be sufficient to assess equivalence between learning conditions. The groups would be equivalent if the 90 % CI of the difference between conditions falls between the predetermined margin of equivalence (-2% to 2%). Three comparisons were performed: 3D virtual environment vs a computerized measure; 3D virtual environment vs a 3D a desktop environment; 3D desktop environment and 3D virtual environment.

Results

For explicit memory, One-way ANOVA pointed out a non-significant main effect of type of learning environment, $F(2, 77) = 0.55$, $p > .05$, with a small magnitude of effect size, $\eta^2 = 0.004$. This result reflected the absence of type of medium environment influence on explicit memory performance, meaning that the participants performed similar on explicit memory measures on a computerized measure, or on a 3D desktop environment or on a 3D virtual environment

In the case of the implicit memory, because we aimed to test whether the type of learning environment yielded equal influences on implicit memory performance, we performed equivalence testing. For the purpose of our study, equivalence is established if the entire 2-sided (1-2α) X 100% CI of the difference in means lies within -0.2 and 0.2. The mean difference between the performance on the computerized learning environment and the 3D virtual environment was -0.06 (90% CI -0.13 to 0.01), which falls between the predefined equivalence margin -0.2 to 0.2. These results pointed out that learning in a computerized environment and in a 3D virtual environment have a similar effect on implicit memory performance. Next, for the comparison between the performance on the computerized environment and the 3D desktop environment the mean difference was -0.02 (90% CI -0.1 to 0.05), which falls again between the predefined equivalence margin -0.2 to 0.2. As expected, results showed equivalent implicit memory performance for learning in a computerized and 3D desktop environment. In the case of the comparison between implicit memory across the 3D desktop environment and 3D virtual environment conditions results show a mean difference of -0.03 (90% CI -0.11 to 0.04) which falls between the predefined equivalence margin -0.2 to 0.2. In line with our expectances, it seems that the effect of learning condition on implicit memory is similar across 3D learning conditions.

Insert Table 2 about here

Discussion

We aimed to investigate the effect of learning environment on explicit and implicit memory performance. The learning environments differed in their level of immersion. Some might consider that the virtual apartment has the highest level of immersion compared to the computerized and 3D desktop environment because it recreates a real environment (Parsons, Carlew, et al., 2017; Rizzo & Koenig, in press).

Previous research has indicated that explicit memory is a slow, controlled process that requires much more cognitive resources than implicit memory (Graf & Schacter, 1985; Payne, 2008). Based on mixed results in terms of task difficulty concerning differences between immersive and non-immersive virtual reality that either show better performance in virtual reality or poorer memory performance (Gamberini, 2000; Lo Priore et al., 2003; Mania & Chalmers, 2001; Neguţ et al., 2016a) we expected that the type of learning environment will impact the explicit memory performance. Contrary to our predictions, the results pointed out no significant differences on explicit memory performance between the participants who learned in the computerized environment or in the 3D desktop environment or in the 3D virtual apartment. This might suggest that the task of learning in virtual environment does not require additional cognitive resources than the classical learning tasks when one relies on explicit memory. Worth mentioning is the fact that our participants had to navigate in the virtual environment in a passive condition. It might be the case that they could not benefit from sensorimotor interaction that improves episodic memory (Brooks et al., 1999; Plancher, Barra, Orriols, & Piolino, 2013). Passive conditions seem to require more cognitive resources as participants do not benefit from an automatic encoding and motor memory specificity compared to those that learn in active conditions (Plancher et al., 2013)

For the implicit memory, we expected a similar performance despite the cognitive load triggered by the difficulty of a learning task because implicit memory is less cognitive costly (Baddeley & Wilson, 1994; Graf & Schacter, 1985; Spataro et al., 2011). As expected, results pointed out equivalence in performance between the three learning environments. This supports our assumption that unintentional and automatic learning in a virtual environment targets the same cognitive resources and has a similar level of task difficulty as classical learning tasks.

Previous studies that tested for differences between virtual reality and computerized tests used healthy samples and focused on explicit recall tests with mixed findings (see Gamberini, 2000; Lo Priore et al., 2003; Mania & Chalmers, 2001). Gamberini (2000) showed significant differences between the two environments on an object recognition task with better performance in the desktop condition, and no significant differences on an object location task. Nonsignificant differences on memory performance between learning in a virtual environment and in a desktop non-immersive environment were reported by Lo Priore et al. (2003). Mania and Chalmers (2001) tested for differences between virtual reality and desktop learning conditions across four states of memory awareness: remember, know, familiar and guess that correspond to sematic and episodic memory. For information recall, the results showed no differences in memory performance under the “remember” state between the virtual reality and desktop conditions, while under the “guess” state there was a better performance in the virtual reality condition. However, when they compared virtual reality and desktop conditions with a simple audio condition, again, no significant differences emerged. For spatial memory, no significant differences emerged. Overall, although the reported results are rather mixed, they may suggest one major trend with no differences in terms of test difficulty between the two types of measures.

Although the studies described above had different virtual scenarios, they all focused on testing the beneficial or the detrimental effects of virtual reality on explicit memory. However, across all studies there is a slightly difference between the modality of stimulus presentation between the encoding and test phases which might have impacted memory performance. More specifically, in the study of Mania and Chalmers (2001) and Lo Piorre et al. (2003) there is a mismatch between the encoding setting (i.e. virtual environment) and memory recall test setting (i.e. paper-and-pencil questions). We also used a cross modal approach with images in the study phase and words in the test phase that allowed us to apply a word stem completion task with the Process Dissociation Procedure. In our study, we identified a similar trend as the studies described above, with no differences in performance between the three learning environments when we tested for explicit memory. This might suggest that for healthy adults learning in a virtual environment has no effect than learning in a traditional setting such as learning items displayed on a computer screen. On the other side, our study was the first one to assess the effects that learning in a virtual environment has on implicit memory. Being the first of its kind, it revealed that the results are similar for both implicit and explicit memory performance. However, because implicit memory paradigm suggests that the implicit memory is less affected by the tasks' difficulty or complexity, our results validate this pattern in a virtual environment.

Limitations and conclusions

Several limitations are worth being mentioned. The first one refers to the amount of control. We used a highly ecological environment such as the virtual apartment and asked participants to learn as many objects as possible while guided through the apartment. Then we compared memory performance with a computerized environment that consisted of the same items from the apartment delivered item by item. This might have caused a non-equivalence regarding the time spent on encoding each item. However, because we wanted to target the performance on a highly ecological assessment measure, we can consider this potential threat to internal validity as an evidence for the ecological validity of the virtual environment-based assessment. Also, we did not ask participants to read aloud each object because it would have been difficult to control for the speed allocated by each participant for encoding in virtual reality. We also did not control for the frequency and the novelty of the items presented in the apartment. Almost half of the objects from the apartment were included in the original demo from EON Reality. However, the list of items that were added into the apartment was carefully inspected to exclude non-frequent and unusual items. The list of items included in the apartment is available (see Appendix 2). Another potential limitation is the cybersickness. Five participants reported at least one severe symptom of simulator sickness. Future studies might take into consideration using virtual environments with better graphic quality in the attempt to increase the presence and to reduce the simulator sickness. Also, other research can replicate our results by applying a Process Dissociation Procedure on different clinical populations. The effect of learning environment on implicit and explicit memory performance might be slightly different among clinical samples compared to healthy controls. Also, we had a mismatch between learning stimuli (i.e. visual stimuli) and test stimuli (i.e. words at test) which might have negatively impacted memory performance. Future studies might use images at the test phase.

To conclude, we found that the type of learning environment does not influence explicit and implicit memory performance. Participants have similar performances on both controlled, conscious processes and uncontrolled, unconscious processes even if they learn on a computerized environment or on a 3D desktop environment with a low level of immersion and or on a 3D virtual environment with an increased level of immersion.

Table 1

Demographic characteristics of participants organized by type of learning environment condition

	Computerized environment (*n* = 29)		3D desktop environment (*n* = 22)		3D virtual reality environment (*n* = 26)		χ^2/F
Gender (% men)	31%		27%		27%		0.13 *ns*
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Age (in years)	24.51	4.14	23	3.36	24.15	4.54	0.90 *ns*
TMT A	25.50	10.86	22.22	6.57	24.04	5.43	0.99 *ns*
TMT B	55.96	44.42	60.04	35.93	61.97	31.16	
Computer operation knowledge	6.34	0.89	6.36	0.84	6.03	1.18	0.87 *ns*
Computer use enjoyment	6.10	1.11	6.18	1.05	6.19	1.05	0.05 *ns*

Note. TMT A = Trail Making Test Part A (Reitan, 1958); TMT B = Trail Making Test Part B (Reitan, 1958), *ns* = *p* > .05.

Table 2

Mean estimates and of A and R

Experiment and manipulation	A		R	
	M	*SD*	*M*	*SD*
Computerized environment	0.17	0.13	0.24	0.17
3D desktop environment	0.19	0.11	0.21	0.14
3D virtual reality environment	0.23	0.11	0.19	0.14

Note. A = unconscious, automatic influences corresponding to implicit memory; R = conscious, controlled influences corresponding to explicit memory

Appendix 1

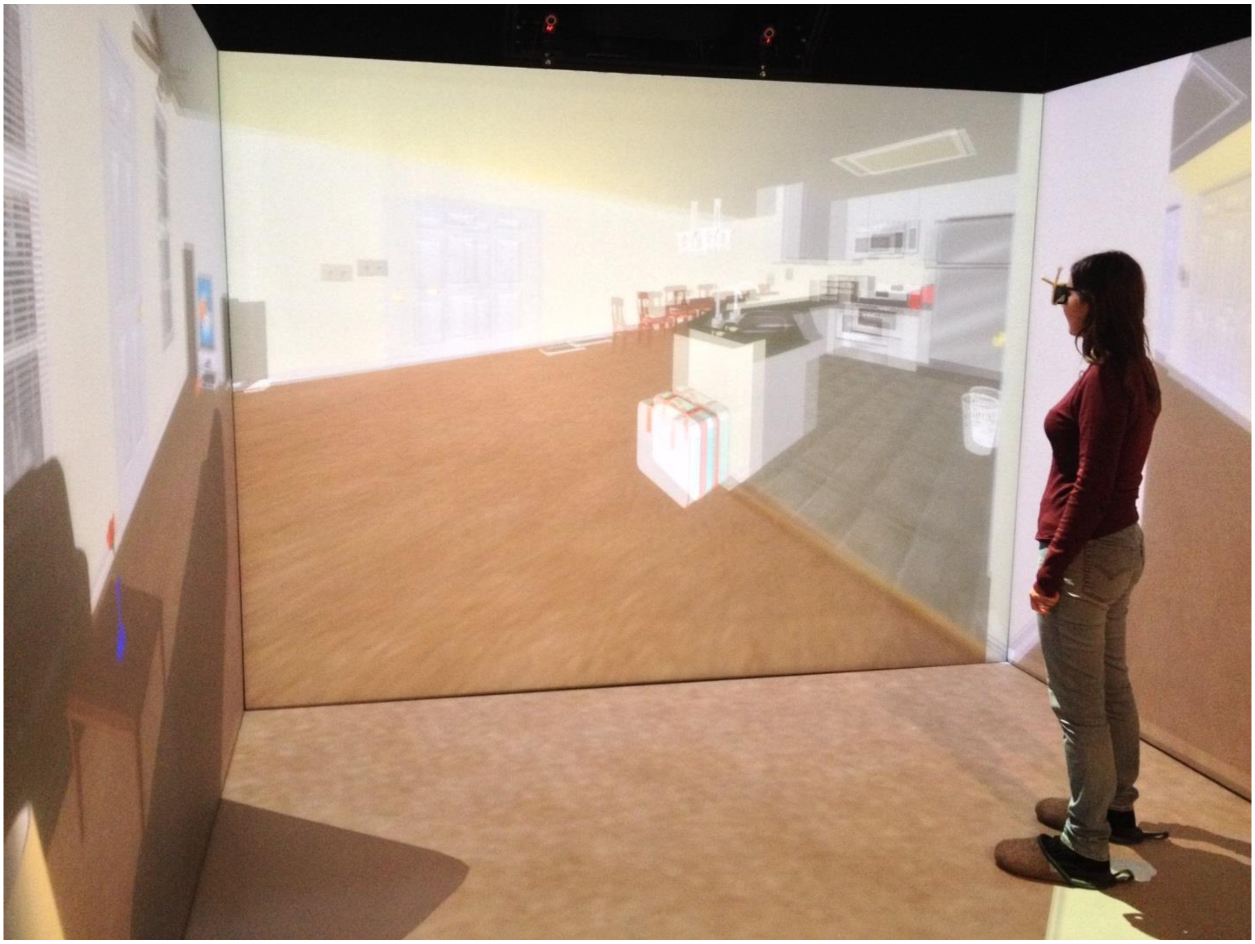
List of items from the study phase

Romanian (*English*)	Stem
aragaz (*stove*)	ar
avion (*plane*)	av
biblioteca (*bookshelf with books*)	bi
briceag (*penknife*)	br
canapea (*sofa*)	ca
cântar (*scale*)	câ
ceas (*watch*)	ce
chiuveta (*sink*)	ch
combina (*cassette*)	co
cutit (*knife*)	cu
disc (*disc*)	di
dulap (*closet*)	du
etajera (*shelf*)	et
fereastra (*window*)	fe
floare (*flower*)	fl
fotoliu (*armchair*)	fo
frigider (*fridge*)	fr
geamantan (*suitcase*)	ge
gunoi (*trash*)	gu
întrerupator (*switch*)	în
jaluzea (*window blind*)	ja
lampa (*light*)	la
lumanare (*candle*)	lu
masa (*table*)	ma
minge (*ball*)	mi
mocheta (*carpeting*)	mo
noptieră (*nightstand*)	no
oală (*pot*)	oa
ochelari (*glasses*)	oc
pantof (*shoe*)	pa
scaun (*chair*)	sc
televizor (*TV*)	te
ușa (*door*)	uș
vaza (*vase*)	va
ventilator (*fan*)	ve

video (*video*)	vi

Appendix 2

The virtual apartment delivered via ICube



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