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A Virtual Reality Test for the Identification of Memory Strengths of Dyslexic Students in Higher Education

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Abstract: Research suggests that Virtual Reality has a key role in the development of new diagnostic tools in neuropsychology and shows great rehabilitative potentials for individuals with specific neurological, intellectual and cognitive disabilities. In the case of dyslexia, a neurodevelopmental reading disorder, the use of Virtual Reality technologies has only been recently documented in a handful of studies. The main focus of these studies has been the identification of visuospatial strengths, the exploration of nonverbal problem solving treatment and the increase of awareness in educators and parents with children with dyslexia. Even fewer are the studies of Virtual Reality and the lifelong memory difficulties of adult individuals with dyslexia. With a more clinical, rather than technological, perspective the goal of this paper was to design specialized tasks in virtual environments to be part of a screening process/assessment of characteristic memory difficulties for undergraduate students diagnosed with dyslexia. Results showed that there were no statistically significant differences in the performance of students with dyslexia and students without dyslexia, a finding which highlights the development and successful use of compensatory memory strategies by the participants with dyslexia. Taking into consideration the real life representations, the multisensory approach, the increased sense of presence, the well-designed tasks and the recorded positive attitude of all participants, the study concludes that the use of Virtual Reality in neurological and neurodevelopmental memory disorders will be innovative and suggests that hands on Virtual Reality applications, become an indispensable part of these deficits' cognitive assessment and rehabilitation.

Keywords: dyslexia, memory, virtual environments, university students, assessment, compensatory strategies
Categories: J.5, H.4.m, L.0.0, L.1.1, L.2

1 Introduction

Controversial, yet fascinating, dyslexia is a challenging developmental learning condition, both for individuals as well as research scientists. The term, like many other scientific terms (ex. diagnosis, symptoms, autism), derives from the Greek language and it literally means "difficulty with words" [Catts and Kamhi (2005), Ott (1997)]. However, and unlike previous perceptions, it is the current understanding that dyslexia is more than a reading disorder/reading failure [Berninger et al. (2008), Ott (1997)]. The syndrome's wide repertoire and dynamic of characteristics, has led dyslexia experts in a scientific debate regarding its profile and definition. Indicative of this situation is the fact that well known diagnostic manuals (such as DSM-IV-TR and ICD-10) as well as different, yet broadly respected, dyslexia organisations and associations (e.g., the International Dyslexia Association (IDA), the American Dyslexia Association (ADA), and the British Dyslexia Association) use and refer to different dyslexia characteristics and definitions. Thus, since the term first appeared in 1887 by ophthalmologist Rudolf Berlin [Ott (1997)], the quest for a valid and commonly accepted definition was ensued by numerous attempts. These definition attempts resulted, according to Hammill [1990], to as much as forty-three definitions, which in their majority reflected the common understanding that dyslexia affects an individual's reading, writing, and spelling skills. However, the conceptualization of dyslexia as a childhood educational condition seems nowadays to be rather narrow [McLouhglin et al. (1994)]. Significant scientific and technological breakthroughs mainly in the medical research field (e.g. PET scans, MRI, fMRI, rCBF techniques) [Flowers (1993), Hynd and Hiemenz (1997), Shaywitz (1996)] have widen the academic perspective of the syndrome's characteristics and origins.

Current studies that focus on brain development, architecture and function have brought to light some complicated, yet common, characteristics among individuals with dyslexia. These neurological findings (e.g. differences in dyslexic and non-dyslexic individuals' hemispherical asymmetry, white and grey matter, brain activation patterns, and brain's metabolic distribution) [Hudson et al. (2007), Deutsch et al. (2005), Heim and Keil (2004), Booth and Burman (2001), Shaywitz et al. (2002)] have offered some solid ground of agreement among researchers in terms of the syndrome's characteristics and definition. However, as many researchers point out, there are some important considerations that should be kept in mind. More specifically, these considerations regard several significant variables such as: the small number of participants in many of studies [Wajuihian (2012), Hudson et al. (2007)], the occurrence of false negative and false positive dyslexia diagnosis, the neuroanatomical nature of the findings (which provide certain clarity in their interpretation, as oppose to psychological and cognitive results), the developmental and therefore dynamic aspect of dyslexia [Hudson et al. (2007)], the brain plasticity in young individuals [Wajuihian (2012)], the role of the environment and impact of (early) intervention and special education [Aylward et al. (2003), Shaywitz et al. (2002)], the restrictions due to the lack of naturalistic tasks and real-life conditions, the light of new scientific and technological advances and the delicate handling of some procedures (e.g. there are very few studies with child population and use of fMRI as it crucial that the participant is motionless during the imaging [Hudson et al. (2007)]. These parameters play a significant role in the different applied research approaches and result interpretation.

The aforementioned breakthroughs and new insights in dyslexia's symptoms and causes are reflected in the syndrome's definition by the National Institute of Neurological Disorders and Stroke: "Dyslexia is a brain-based type of learning disability that specifically impairs a person's ability to read. These individuals typically read at levels significantly lower than expected despite having normal intelligence. Although the disorder varies from person to person, common characteristics among people with dyslexia are difficulties with phonological processing (the manipulation of sounds), spelling, and/or rapid visual-verbal responding. In individuals with adult onset of dyslexia, it usually occurs as a result of brain injury or in the context of dementia; this contrasts with individuals with dyslexia who simply were never identified as children or adolescents. Dyslexia can be inherited in some families, and recent studies have identified a number of genes that may predispose an individual to developing dyslexia" [NINDS (2011)]. According to another well-known working definition of Lyon, Shaywitz and Shaywitz, "dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction" [2003:2].

Besides the characteristics listed in dyslexia's updated and lengthy definitions there are also many other symptoms worth mentioning. These symptoms include difficulties in laterality (which refers to the preference shown for the left or right side of the body resulting to cerebral dominance), memory, and organization, as well as decreased (fine and gross) motor, spatial and temporal orientation skills [Miles (1983), Ott (1997), Reid (1998)].

As far as memory is concerned, i.e. an individual's mental ability to encode, store and retrieve information [Gering and Zimbardo (2002)], in the case of dyslexia, the memory deficits and their manifestations are so prominent in the syndrome's profile, that they are considered to be both typical indicators of its existence as well as reliable indicators for a positive diagnosis in a diagnostic battery [McLouhglin et al. (1994), McLouhglin et al. (2002), Ott (1997)]. However, and besides the research done in the memory field overall, the multidimensional role and complex function of this fundamental learning mechanism in the life span of an individual with dyslexia, has yet to come to our fully understanding. This is another issue, the lifetime difficulties an individual with dyslexia faces even in his/her adult life, which the present study tries to address.

Even a brief literature review reveals that, the majority of the dyslexia related studies describe preschool and school age children [Mortimore and Crozier (2006), Price (2006)]. However, there has been a shift of interest in the older dyslexia population and in particular the dyslexic students who are enrolled in higher education. This research turn is, among others, attributed to various recent educational legislations, such as the "Individuals with Disabilities Education Act" [USA 1997] and the "Special Education Needs and Disability Act" [UK 2001], that protect disabled students / students with learning disabilities from any kind of discrimination and inaccessibility [Habib et al. (2012), Paul (2001)]. Therefore, there is a consensus in the scientific community of the importance of the study of the dyslexic population, as well as of the fact that relevant research needs to expand and include adults with dyslexia [McLouhglin et al. (2002), (1994)].

Information and Communications Technologies (ICT) are considered to be powerful tools for the assessment and intervention of learning difficulties, including dyslexia. They provide safe and controlled environments, motivation, high level of interactivity, immediate feedback, and contribute to the improvement of visual processing skills and short-term memory or working memory inadequacies [Phipps et al. (2002)]. People with special needs can be benefited by ICT supported learning, which can provide them accessibility to mainstream inclusion [Istenic Starcic and Bagon (2013)].

As part of ICT, Virtual Reality (VR) technologies are often suggested in various studies since the 1990s, as the new means for the development of sensitive neuropsychological assessment and intervention tools [Pugnetti et al. (1998)]. However, in the case of dyslexia, there have been very few studies with the implementation of VR technologies. The relevant research that has inspired and supported our study is presented below.

1.1 Virtual Reality and Visuospatial Abilities in Dyslexia

As far as the dyslexic's visuospatial abilities are concerned, there are studies in this particular area which suggest that individuals with dyslexia demonstrate spatial strengths only in comparison to their verbal abilities [Palmer (2000), von Károlyi et al. (2003)] or even no strengths at all [Everatt et al. (1999)]. However, recent studies support that individuals with dyslexia can demonstrate superior visuospatial abilities [Wolf and Lundberg (2002)], a finding reinforced by neuroanatomical evidence revealing differences in visuospatial related regions in the brain of dyslexics [Galaburda et al. (1985)]. Moreover, experts suggest that these visuospatial abilities of individuals with dyslexia could not have been earlier addressed due to the absence of specialized and sensitive real life spatial ability tests [Winner et al. (2001)]. In 2007 Brunswick and Martin provided some first evidence in that direction. In their small scale study they tested the visuospatial abilities of dyslexic men who demonstrated better results when real life tasks where administrated.

Inspired by the aforementioned findings Attree et al. [2009] performed an exploratory study which compared the visuospatial strengths of twenty-one adolescents with dyslexia and twenty-one adolescents without dyslexia. For the testing of the visuospatial abilities of all participants, two different types of tests were administrated to both groups: a) a computer-generated pseudo real life virtual reality test and b) a standard paper-and-pencil test. Regarding the paper-and-pencil assessment, it included the "Pattern Construction Test" and the "Recall of Designs Test" from British Ability Scales II (BAS II) [Elliott et al. (1997)], whereas in the virtual test, participants had to navigate themselves in a virtual four room (bedroom, music room, lounge, and kitchen) bungalow, which was designed for that study's needs. All participants were asked to find a route through the virtual rooms, recognize and name them, detect/identify a specific object (a toy car), remember how many rooms they explored and finally construct the plan of the virtual bungalow on a board. The statistical analysis of the performance scores of the dyslexic group and the non dyslexic group in the virtual reality test and the paper-and-pencil test revealed that the adolescents with dyslexia performed almost as good to the non dyslexic group when their spatial abilities were paper-and-pencil tested, whereas in real life spatial tests their performance was statistically significantly higher than the non dyslexics. The researchers suggest that their results should be "considered with caution". However, they believe that sensitive technological approaches, like the virtual environments they implemented, and future research in this field will reinforce their finding of visuospatial strengths in individuals with dyslexia.

Finally, remaining in the broader area of the visual processing abilities of individuals with dyslexia, Sigmundsson [2005] attempts to address them from a different perspective. More specifically, he exposed ten dyslexic and thirteen non-dyslexic young adults to a safe virtual driving environment and relevant visual stimuli (i.e. road, road signs and surroundings). Thus, using a car simulator he tested and compared the response time of the participants in two driving simulated conditions. Participants would sit inside a model car and view a video screen. In this video screen, two different driving scenarios were presented. Drivers had to detect and respond appropriately to the appearing road signs, while maintaining a suitable distance from the vehicle ahead. The non-parametric statistical analysis of the study's results showed that non-dyslexic drivers had significantly better performances than the dyslexic participants. Therefore, given that dyslexics needed more time to respond to the presented stimuli, Sigmundsson supports that these individuals might have a visual processing deficit. He suggests that this impairment not only affects their reading abilities, but also their perception of rapid environmental changes, like responding to a road sign while driving. Nevertheless, Sigmundsson clearly states the need for further research in this particular field.

1.2 Virtual Reality and Nonverbal Problem Solving in Dyslexia

This particular study of Winn et al. [2006] was actually part of a larger research that focused on the impact of instruction on the phonological and written skills in children with dyslexia. Its goal was to examine whether young dyslexic students could successfully construct mental representations of demanding marine life phenomena from a computer generated three-dimensional (3D) simulation which would be supported by a nonverbal curriculum. Twenty-four students attending 4-6 grades were equally divided in two groups, the group of 12 students diagnosed with dyslexia and the group of 12 students without dyslexia (i.e. good readers). All students attended an everyday three hour summer oceanography class for two weeks. A quarter of each lesson involved a virtual ocean simulation and the remaining teaching time was related to hands-on, non-verbal problem solving tasks. As far as the marine simulation is concerned, the researchers used the highly visual and interactive Virtual Puget Sound [Winn et al. (2002)]. The results suggest that with the use of virtual simulations children with dyslexia appear to effectively develop visual decoding skills through the activation of different brain resources that eventually enable them to construct spatial mental models equivalent to those constructed by their non-dyslexic peers. It is worth noting that the connection between dyslexia and the visual system is not yet fully understandable due to the complex role of different cerebral cortex areas (e.g. V1) and the brain plasticity in children [Werth (2006), (2008)].

As earlier mentioned, Winn's et al. [2006] findings were also included in the teams' complete publication of both parts of their research in 2007 [Berninger et al. (2007)]. Besides the aforementioned findings, additional reinforcing evidence was mentioned in this latter comparative research, in regards to the use of virtual reality. In particular the researchers suggest that word spelling was improved when spelling instruction had an explicit orientation on orthography or morphology and unexpectedly when the implementation of the hands-on engaging science problem resulted to the improvement of the phonological working memory.

1.3 Virtual Reality and Dyslexia Awareness

Although there have been numerous studies documenting parents' [Dyson (1996)] and teachers' [Hornstra et al. (2010), Tsovili (2004)] attitudes towards dyslexia, there has not been any research focusing on increasing awareness of the specific reading challenges an individual with dyslexia experiences.

One of the first studies that aimed in this area was of Passig et al. [2008]. Their goal was to design virtual reality simulations and test their effectiveness in terms of increasing parental awareness of the difficulties faced and errors demonstrated by dyslexic children. For this reason, the researchers designed ten virtual environments, equally portraying the ten distinct categories of dyslexia (1. visual letter agnosia, 2. neglect dyslexia, 3. visual dyslexia, 4. letter position dyslexia, 5. attentional dyslexia, 6. letter by letter dyslexia, 7. surface dyslexia, 8. phonological dyslexia, 9. semantic access dyslexia, and 10. deep dyslexia) presented in Friedmann-Gvion's taxonomy [Friedmann and Gvion (2001), Gvion and Friedmann (2004)]. According to the research design, 67 parents of children with dyslexia formed the two study groups. The first group, i.e. the experimental group, consisted of 37 parents, who were asked to navigate through the aforementioned ten immersive simulations. On the other hand, the second group of 30 parents, i.e. the control group, watched a documentary film in which difficulties similar to those that appeared in the virtual constructions were presented. Both groups filled Shavit's cognitive questionnaire (The Text as Seen by the Dyslexic Child) [2005], before and after the intervention. In addition, the experimental group was interviewed, likewise before and after its virtual navigation. The study supports that the parents who virtually experienced the dyslexic's difficulties showed significantly increase levels of awareness in comparison to the group of parents who only watched the relevant documentary.

In 2010, Passig, reproducing a similar research design as the one presented in the case of parents' with dyslexic children awareness [Passig et al. (2008)], suggested the use of virtual reality in terms of raising teachers' dyslexia awareness. Thus, an experimental group of 40 teachers navigated through 10 virtual simulations of Friedmann-Gvion's taxonomy of dyslexic errors, whereas the equivalent control group of 40 teachers watched a film about dyslexia. All 80 teachers filled questionnaires before and after their intervention and only the experimental group was additionally interviewed after the completion of their virtual navigation. In conclusion, like in the parents' VR dyslexia awareness study, these results also revealed improved awareness in the case of teachers who experienced the virtual simulation of dyslexic difficulties, as oppose to the teachers that watched the relevant movie. Passig's findings are in agreement with Shavit's [2005], who found that the participant teachers in her study increased their awareness on the cognitive, emotional and social impact reading difficulties have on the dyslexic student.

Based on the powerful features of VR and the few, but significant findings on the usage of Virtual Environments (VEs) to dyslexic populations, our research attempts to study and detect specific memory characteristics in adults with dyslexia during their interaction with virtual environments, specially designed for this purpose.

2 Materials and Methods

The aim of this study was the investigation and detection of a) memory difficulties and skills in undergraduate students with dyslexia, and b) compensatory memory strategies they potentially develop through their interaction with VEs.

For the needs of the study, the VIRDA-MS (VIrtual Reality Dyslexia Assessment-Memory Screening) environment was designed and developed. VIRDA-MS's target was to rapidly and successfully identify the aforementioned memory deficits, thus contributing to the overall evaluation process, and formulation of a complete and individualized dyslexia profile. Complex and creative mechanisms, known as "compensatory strategies", i.e., "methods of processing information that allow individuals to achieve goals using alternative means" [Lyon (1995)] were also documented through the screening process. These mechanisms help individuals to cope with everyday memory challenges, and therefore they have the potential of being utilized in intervention approaches, both for adults and children. Moreover, according to McLoughlin et al. [2002] compensatory strategies "should in fact be seen as a positive and deliberate approach to finding and applying immediate and alternative solutions" [p. 34]. Thus, they help individuals with dyslexia to succeed in tasks regarding the area of their particular difficulties and/or show remarkable abilities, in matters of compensation, in other domains not directly related to their impairments [Bacon and Handley (2010), Singleton et al. (2009)].

2.1 Participants

Seven (7) University students with dyslexia and seven (7) university control students, volunteered to participate in this research. All students were at that time enrolled at the University of Ioannina (Greece) and where recruited through an open call for the research in cooperation with the University's Departments administrative and secretary services.

The group of dyslexic students consisted of four male and three female students, whereas the control group was formed by three male and four female students. All dyslexic participants had a dyslexia diagnosis through an official psycho-language assessment provided during their primary or secondary schooling by multidisciplinary teams of official state facilities [Habib et al. (2012)].

2.2 Measures: Virtual Environment Test (VIRDA-MS)

In our study, three memory systems were examined: a) short-term memory, b) working memory, and c) long-term memory. Three specialized tasks were designed for the evaluation of each one of the aforementioned memory systems respectively, with the contribution of VR. The Superscape Do3D^{TM} 5.10 software package was used for the development of the administrated virtual environments. The developed virtual environments were displayed on a laptop and the user was able to freely navigate around the environments by using the navigation bar of the software. It is worth mentioning that the user friendly Superscape VRT software, as well as similar environments and virtual tasks have been successfully implemented in several previous studies, including populations with learning difficulties [Attree et al. (2009), Brooks et al. (1999), Rose et al. (2000)]. Moreover, the transition from one environment to another was supported by accessible, informative and dyslexia friendly hyperlinks [Habib et al. (2012)].

As far as the examination of the short-term memory is concerned, two identical simulations of the inside of a two floor house were used [Figure 1]. In the first simulation, six (6) groups that respectively comprised of four (4) to nine (9) semantic stimuli (objects) were consecutively placed inside the house. Each one of these groups represented an equal number of sequences that the participants were instructed to memorize. Even though an item might occur in more than one sequence, no item was repeated in the same sequence. The administered semantic stimuli were twenty-one (21) items (piano, chair, bottle, clock, toy house, key, lamp, computer screen, candlestick, toy car, flower pot, camera, globe, pawn, boat, flower, speaker, ball, dice, wardrobe, and refreshment can). Similarly, in the second house simulation, six (6) groups that respectively comprised of four (4) to nine (9) non semantic stimuli (geometrical shapes) were placed consecutively. The nine administrated non-semantic stimuli (sphere, cube, cylinder, cone, trapezoidal, diamond, pyramid, arch, ring) were of the same color in each sequence. In both houses designed for the short-term memory examination, the navigation strategies included a staircase scenario, which has also been used effectively in other studies [Groenewegen (2008)]. As the difficulty of the administrated sequences hierarchically escalated, the participants used a staircase to reach another level of more demanding sequences in the upper floor of each one of the virtual houses.

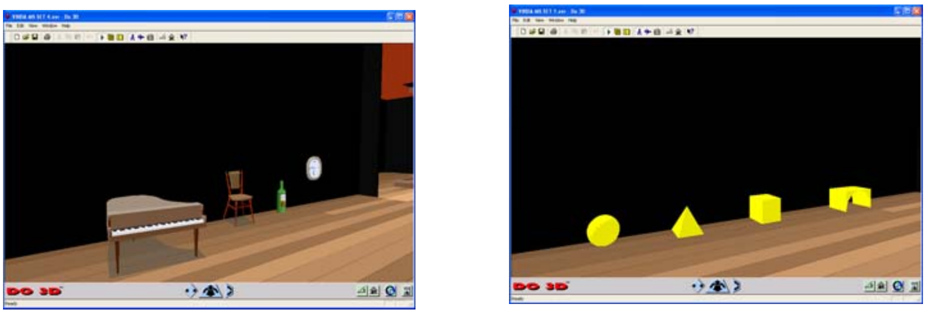

Figure 1: Snapshots from the virtual rooms with the short-term memory subtests (semantic and non-semantic)

In the case of the working memory test, two VEs similar to the ones described above were used. Thus, a two floor virtual house with six (6) hieratically difficult semantic sequences and respectively a second identical two floor virtual house with six (6) non semantic sequences were designed. The administrated stimuli (semantic and non-semantic) were the same as in the case of the short-term memory screening, although the items' combinations in the examined sequences were different. A staircase scenario was also used in both of these virtual houses.

Finally, for the evaluation of the long-term memory system, the user navigates in two identical polygonal virtual rooms, each one resembling an art gallery with rather unique paintings [Figure 2]. In the first room of semantic stimuli, eighteen (18) two-dimensional black and white images (flower, tree, snail, bus, boat, cup, cheese, egg, cupcake, screw, zebra, cow, scissors, cookie, hat, ice cream, bottle, and glove) were placed. The administrated images were carefully derived by visual material suitable for adults [Goodglass and Kaplan (1983)]. In the second non-semantic stimuli room, thirteen (13) geometric shapes (square, cycle, triangle, rectangle, trapezoid, parallelogram, rhombus, oval, pentagon, hexagon, heart, star, four-point star) were used. Both semantic and non-semantic room comprised of seven (7) sequences that respectively included three (3) to nine (9) stimuli. The items/sequences were consecutively placed inside the rooms as their difficulty hieratically escalated. One level virtual rooms, like the ones constructed for the evaluation of the long-term memory system have also been used in relevant studies [Attree et al. (2009), Brooks et al. (1999), Rose et al. (2000)].

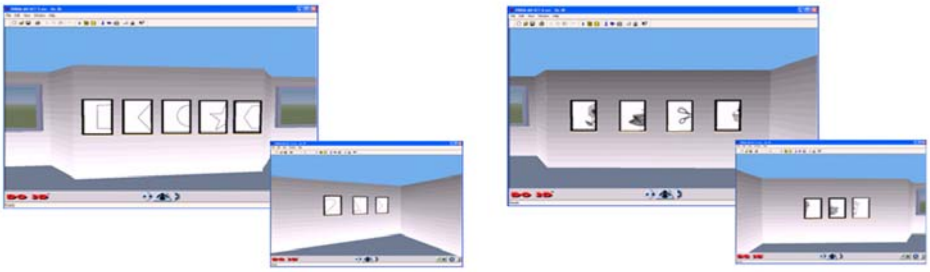

Figure 2: Snapshots from the virtual art gallery and its long-term memory subtests

2.3 Procedure

Initially participants arrived at the University's computer lab, where they were informed of the purpose and the process of the study. Afterwards, they had the opportunity to freely navigate inside virtual environments similar to those that they would find in the VIRDA-MS application in order to become familiar with the environments and the navigation process. The participants' responses were orally provided and were subsequently recorded by the researchers in a special protocol form. After the completion of the tests, all participants went through a short personal and non-structured interview, during which they described the memory strategies they implemented in order to cope with the given tasks. Finally, they were requested to complete the short "VIRDA-MS Questionnaire" for the recording of their opinion, impression and attitude in regards to specific features of the implemented virtual environments and the application per se (see Annex).

As far as the VE test is concerned, the three hierarchically structured tasks started with an easy level and gradually escalated their level of difficulty. Each test corresponded to a memory subsystem and consisted of two subtests, one with objects with semantic content and another with objects without semantic content (geometric objects). Thus, in the short-term memory test the task of "Direct Visual Sequence Recall" (forward digit span) was administrated. Students were asked to successfully call to their mind and in the correct sequence the presented visual stimuli [Figure 1]. More specifically, the participants had to carefully look at the computer screen for up to seven seconds and then navigate themselves to the closed vacant space of the virtual house, i.e. an area with no objects. Afterwards, the students had to orally name and enumerate the given stimuli in the order they were presented.

This test consisted of two subtests, the first of which included six colored sequences of the 3D visual stimuli with semantic content and the second one also consisted of six color sequences of the 3D visual stimuli without semantic content. The recording of the participants responses were made by the researchers in a special designed form.

Similarly, for the second memory test, namely the test of working memory, the task of "Direct and Reversed Visual Sequences Recall" (backwards digit span) was administrated. In this second memory test the students were asked to successfully call to their mind and with the correct reversed order, the 3D semantic and non-semantic visual stimuli presented. It is worth noting that such activities are tightly associated with dyslexia, and are considered to be particularly sensitive indicators of the syndrome's positive detection [Fawcett and Nicolson (1998), McLouhglin et al. (2002)].The procedure steps were identical to the ones described in the short-term memory test. As far as the time limit is concerned, the researchers used a chronometer (in both short-term and working memory tests) to ensure that none of the participants would exceed the given time. All students stayed within the particular time framework and afterwards easily transferred to the nearby vacant area. There was a special concern regarding the architecture of the virtual houses, so that the students' navigation would be facilitated at all times. Again, the oral responses of the participants were recorded by the researcher in the aforementioned form.

Finally, the task of "Visual Stimuli Synthesis" was administrated, for the evaluation of long-term memory. In this third memory test the participants were required to successfully recognize the pictures (semantic and non-semantic) resulting from the composition of two separate images [Hitch et al. (1995)]. This test also consisted of two subtests. The first subtest included seven sequences where only the left half of the semantic visual stimuli was presented. Similarly, the second subtest of the long-term memory consisted of seven sequences where only the left half of the non-semantic visual stimuli was demonstrated. Each one of these two subtests was divided into two phases. Initially, the participants were presented with the left half of the targeted semantic or non-semantic visual stimuli of the sequence. The participants, having carefully observed the left half of the visual stimuli included in the sequence, navigated to the second phase, where they were presented with three half visual stimuli. One of these three visual stimuli correctly corresponded to one of the previously presented left half stimuli of the first phase of the task. Finally, the participants were asked to identify the picture that emerged from the combination of these two separate halves. Their oral answers were recorded by the researcher in the relevant form.

3 Results

Participants' overall impression of the VIRDA-MS application was quite positive, and in some cases, even enthusiastic. There were frequent positive comments about the playful and pleasant character of the tasks. Concerning the participants' responses to the VIRDA-MS Questionnaire, special mention should be made for the fifth question regarding the participants' assessment of their navigation experience in the virtual environments. Thirteen (13) out of the fourteen (14) participants rated their experience "easy" to "very easy", whereas one described it as "moderate". Concerning the typical question for the sense of presence "during your navigation did you feel that you were in an environment or you were watching a series of images" [Slater (1999)], twelve (12) of the fourteen (14) students answered that they felt like being in an environment.

The statistical analysis of the collected data was performed by the SPSS 16.0. A non-parametric Mann-Whitney U test was conducted to detect differences between the control and the experimental groups.

3.1 Short-term memory

In the case of non-semantic visual stimuli the difference between the control and experimental groups was not significant (Z= -1,483, p=0,165). A non-significant difference was also found for the semantic visual stimuli (Z= -1,590, p=0,112). Thus, students with dyslexia had similar overall performance to students without dyslexia in the test and subtests of the short-term memory system.

3.2 Working memory

In the case of working memory, the difference between the control and experimental groups was not significant for the non-semantic visual stimuli (Z= -0,585, p=0,559). A non-significant difference was also found for the semantic visual stimuli (Z= -0,773, p=0,439). Therefore, students with dyslexia had similar overall performance to students without dyslexia in the test and subtests for the working memory.

3.3 Long-term memory

For the last set of results, the long-term memory results, the statistical analysis showed that there was no significant statistical difference for either the long-term memory non-semantic visual stimuli task (Z= -0,903, p=0,367) or the long-term memory semantic visual stimuli (Z= -1,209, p=0,227). The students with dyslexia had similar overall performance to the students without dyslexia in the test and subtests of the long-term memory system.

3.4 Memory strategies

A finding of significant interest and importance was the study's recording of several memory strategies successfully implied by both of the students groups [Table 1]. As it can be seen, all the participants demonstrated common strategies, whether the students of the experimental group appeared to have developed slightly more strategies, also known as compensatory memory strategies.

The implemented strategies were revealed to the researchers in a short, individual, non-structured and open-questioned interview (e.g. "What did you do to remember the presented objects in the first task?"), that followed the completion of all memory tasks. During the interview, the participants described and elaborated on the memory strategies they implemented. The naming of the memory strategies derives either by the relevant literature or the authors themselves. In the case of lack of specialized terminology the authors tried to the best of their ability to appropriately name those strategies. The interview answers of the participants were recorded in written by the researchers during the interview.

"Counting of items number" refers to a simple memory technique where the individual counts the number of items included in each group (e.g., chair-clock-flower-piano is a group of four items).

"Item grouping in pairs or triads" refers to the "chunking" of information into groups of two or three bits of information. For example, it is easier to remember long sequences of information e.g., telephone numbers, tax identification numbers, and passwords when they are broken into small chunks.

"Item grouping based on common characteristics" refers to the grouping in of the sequence's items according to associations; in other words making connections between different items based on selected features (e.g., utility). For example, associate a lamp and a candlestick through their common use for lightening. Another approach to this grouping strategy would not be to organize the items based on the same and common feature, as aforementioned, but to group them according to a joint technique, for example the use of the first grapheme or phoneme of the items, e.g., chair-clock-computer-candlestick all start with the letter "c".

"Self-sequence repetition" is a reference to an individual's internal self-repetition of a sequence. In our study sequences were visually rehearsed. The participants remained silent and did not subvocalize, as documented by the researchers that were present at all times during the testing. Therefore, there was no verbal/auditory feedback while they implemented this strategy.

Memory strategies	
Students with dyslexia	**Students without dyslexia**
Counting of items number	Counting of items number
Item grouping in pairs or triads	Item grouping in pairs or triads
Item grouping based on common characteristics (e.g., initial phonemes, semantically, utilitarian)	Item grouping based on common characteristics (e.g., initial letter)
Self-sequence repetition	Self-sequence repetition
Eye-closing during self-sequence repetition	Eye-closing during self-sequence repetition
Story creation	

Table 1: Memory strategies used by the two groups

"Eye-closing during self-sequence repetition" was a technique recorded when individuals closed their eyes in order to exclude any (external/disruptive) stimuli, therefore reinforce the visual rehearsal of the administrated sequence.

"Story creation" refers to recalling information through storytelling. Individuals focused on important elements of the presented information, often arranging them in a logically sequenced formation. This memory strategy is considered to be of great creativity, and when mastered, a rather effective one. The more creative a story is, the better the likelihood of each one of the elements used, to reinforce the memory of the next item, thus efficiently remembering even larger sequences. This memory strategy was demonstrated only by the group of the students with dyslexia, and its implementation appeared to be rather helpful, exciting challenging and pleasant, especially in the non-semantic sequences case.

4 Conclusions

The purpose of this study was the investigation and identification of memory strengths in undergraduate university students with dyslexia, through their interaction with specially designed virtual environments. Moreover, keeping in mind the current rational supporting the use of VR technologies as powerful clinical tools [Rizzo et al. (2012)], we attempt to present from a clinical point of view the unique features of virtual reality (e.g., freedom of navigation in a controlled and safe environment) and their diagnostic potential in the dyslexia research field. In addition, given the fact that this is a pilot study, with a small research sample, we try to objectively present and critically compare its findings. Nevertheless, we support that the low number of participants does not affect the reliability and validity of our results, as a careful methodological research planning preceded each phase of the study.

Moreover, it is common in this type of research, i.e. studies with special populations, to report small participant numbers [Parsons et al. (2009), Hudson et al. (2007)]. This is attributed, among others, to: (1) the low percentages of the particular special populations in regards to the general population (in other words the frequency of the disorder), (2) the heterogeneity in the population per se, (3) the lack of specialized assessment batteries combined with the development and use of compensatory strategies (therefore the diagnosis escape) for some individuals [Singleton et al., 2009], (4) the stigma of the disorder on the dyslexic himself/herself and his/her family [Macdonald (2010), (2009)], as well as (5) the different scientific goals and methodological approaches of each study. It is understandable that these conditions, as well as the prevailing notion that dyslexia is a children's disorder that mainly impairs the individual's academic skills, also reflect to the spectrum and orientation of relevant and specialized literature. Keeping in mind the aforementioned restrictions along with our thorough literature search, we attempt to interpret our findings to the best of our knowledge and ability and at no point to generalize them.

Thus, the literature review did not trace similar studies with our research's triad of variables: (adult) dyslexia - memory - virtual reality. However, significant research has been documented regarding dyslexia and memory [Ott (1997)]. This group of studies focuses predominantly in children, whereas in the case of studies of dyslexia and virtual reality there has been a small number of interesting reports regarding both adult [Brunswick and Martin (2007)] and child [Attree et al. (2009), Winn et al.

(2006)] populations. Nevertheless, there has been very limited research regarding the use of VLEs in dyslexia [Habib et al. (2012)] either as an assessment tool or an intervention technique.

As far as memory performance in adults with dyslexia is concerned, McLouhglin et al. [1994] suggest that dyslexic adults can in some cases perform as well as non dyslexics. The three dyslexia experts provide evidence from their longtime clinical experience with dyslexic adults supporting that these good performances are observed when: a) the administrated tasks focus on memory skills, b) visual stimuli are involved, and c) the examinee is considered to be a successful dyslexic (i.e., adults with dyslexia who have achieved both professionally and personally, through hard work, an understanding of their weaknesses as well as strengths, and development of coping strategies) [McLouhglin et al. (1994), (2002)]. Our results regarding the good performance of dyslexic participants in the visual memory tasks are in agreement with the aforementioned suggestions of McLouhglin et al. [1994].

Moreover, in matters of the similar good performances of both groups of participants, it should be noted that the presented results could be considered as inconclusive. Nevertheless, literature review reveals few relevant VR studies with mixed, inconclusive [Reid (2002)] or even negative results [Parsons et al. (2009)]. In the case of our research, we suggest the aforementioned findings reflect two significant clinical and research factors i.e. the dyslexic participants were successful adults, and they had developed and efficiently implemented compensatory strategies.

Additionally, Torgesen and Houck [1980] suggest that when individuals with dyslexia are given memory tasks comprising of visual sequences, they do not demonstrate their characteristic memory sequencing (i.e., digit span) difficulties [McLouhglin et al. (1994), Miles (1983), Ott (997)]. Moreover, the aforementioned study suggests that its findings are particularly evident when the presented visual stimuli are difficult to be given verbal labels. This finding is also supported from our study and the good performance of dyslexic students, particularly in the non-semantic sequences (i.e. geometrical shapes).

Nevertheless, in our case, the dyslexics' good performance finding could presumably be considered as a controversial result, given the fact that there are the several documentations of dyslexics' low scores in similar memory tasks [McLouhglin et al. (1994), (2002), Miles (1983), Ott (1997)]. However, as McLouhglin, et al. accurately underline, "although some behaviours can be described as being typical of a dyslexic, it is possible for someone to develop strategies that obscure obvious signs. Some adult dyslexics will appear to be very good at remembering: paradoxically, they have a good memory because their memory is poor […], some adult dyslexics seek out very effective ways of improving memory and, […] they develop an above average ability to recall material" [1994]. Both our results as well as our recording of compensatory strategies [see Table 1] demonstrated by the dyslexic participants, are consistent with McLouhglin's et al. findings [1994].

Moreover, it is worth mentioning that our dyslexic participants used the aforementioned memory strategies in a more methodic way, occasionally combining more than one at a time, and generally in a better sense, compared to the students without dyslexia. Moreover, the development and use of compensatory strategies by dyslexics is also supported by several other studies [Gilroy and Miles (1996), Ingesson (2006), Kirby et al. (2008), McLouhglin et al. (2002), Shaywitz et al.

(2003)]. Another aspect for the compensatory argument is provided by Wolf and Lundberg [2002]. The researchers suggest that the “evolutionary resistance of dyslexic genes” is responsible for the (superior) abilities/strengths (or even in some cases talents) demonstrated by dyslexic individuals.

We believe that the unique multisensory characteristics of the aforementioned virtual environments, as well as the ones developed in our study, played a significant role in the dyslexic participants’ high scoring. The effectiveness of multisensory approaches (i.e., the simultaneous, direct, and powerful use of as many as possible sensory pathways to the brain) in the compensation of memory inefficiencies as far as dyslexia is concerned has also been recorded [McLouhglin et al. (1994), (2002), Ott (1997)]. Moreover, the use of senses (e.g. eyesight, hearing, kinaesthesia) as learning aids and their beneficial educational role aids in general and in dyslexia in particular, has also been documented [Kátai et al. (2008)].

Furthermore, we support that the similar scores between the two research groups, as well as the overall good performance of the dyslexic group, bring to light specific memory strengths of these individuals. In the mean time, the development and effective use of compensatory memory strategies on their behalf, is also revealed. The assessment and documentation of the aforementioned strengths and strategies, provide a basis for future work (e.g. fMRI studies). More specifically, researchers could explore the neurological mechanisms and alternative brain activation patterns that the particular dyslexics have developed and mastered through self-training. Moreover and from a therapist’s point of view, the appropriate adjustment and inclusion of these mechanisms in an individual intervention plan could prove to be rather beneficial for young school aged dyslexics. The proposed strategies embody years of experience and experimentation by successful adult dyslexics. Thus, dyslexic students who often struggle with these difficulties, while lacking of experience and knowledge of effective techniques, could be helped in that direction. These techniques could reduce the time, effort, and frustration of their trial and error approach, when appropriately introduced by the therapists and successfully executed by the neuroplastic brain of young dyslexics.

In reference to dyslexia and virtual reality studies, our results agree with those of Attree et al. [2009], and Brunswick and Martin [2007] who found that dyslexic’s “may exhibit superior visuospatial strengths on certain pseudo real-life tests of spatial ability” and as a result they received high scores in visuospatial and memory tests when interacting with virtual environments. Respectively, our study’s evidence is also consistent with those provided by Winn et al. [2002] associating good performances in visual tasks involving dyslexics and virtual reality technologies. This can be attributed to the motivational, engaging and joyful character of real-life virtual environments, like the ones administrated in our study, opposed to traditional paper-and-pencil tests.

Finally, regarding the virtual environments and participants’ answers to the VIRDA-MS Questionnaire, it appears that they were enjoyed and appreciated by the participants as they were both playful and required no writing, an activity which individuals with dyslexia are often reluctant to do [McLouhglin et al. (1994)].

5 Future Work

There has been a rapid increase of ICT supporting studies involving special needs populations in the last four decades. Although the development of this research field is significant, the majority of the relevant studies focus on learning disabilities in groups with specific or mixed disabilities [Istenic Starcic and Bagon (2013)]. It has been highlighted that there is little and relatively recent research in the use of virtual reality technologies and dyslexia. Our study, although exploratory, provides some insights that have the potential to form the basis of larger-scale investigations with further qualitative and quantitative evidence on this matter [Habib et al. (2012)]. As far as the use of virtual reality for new diagnostic tools is concerned, we suggest the comparative study of the environments developed in this research, to reliable and validated traditional (i.e. paper-and-pencil) neuropsychometric tools for memory assessment. It is expected that the reader critically approaches our following positions and suggestions that do “not imply differences in scientific quality between studies, i.e. that some authors work with more diligence and are rewarded with findings other groups cannot obtain” [p. 10], as Heim and Grande [2012] felicitously state about dyslexia research.

In this point, we would like to mention once again that our study was pilot. Moreover, it had a clear and specific focus on the threefold (adult) dyslexia - memory - virtual reality, with an original approach that had not been previously documented in English peer-reviewed literature. Nevertheless, we acknowledge and report this particular methodological matter and believe to be a valuable recommendation for future research. It is consideration also stated in other VR relevant clinical researches [Parsons et al. (2009)]. We strongly believe this proposal will provide further support to our findings and suggestions. Thus, as shown by relevant studies, we propose that real-life simulations will prove to be more sensitive and revealing than the traditional paper-and-pencil tests [Pugnetti et al. (1998)].

Furthermore, in a critical approach of our assessment procedure, the VIRDA-MS per se and the study’s results, we would like to stress another matter that we believe it is of particular importance. That is the error-seeking base of several diagnostic protocols. Nevertheless, as McLoughlin and colleagues [2002] state, the purpose of assessment “is to identify abilities, including strengths and weakness” [p. 32], “promote self-understanding and should be a positive rather than a negative experience” [p. 43]. We believe our study reflects these values in a plethora of researches that embrace the aforementioned philosophy and refer to only one aspect of dyslexia; that of what dyslexic individuals cannot do. Moreover, as Gerber et al. [1992] and Spekman et al. [1992] have acknowledged almost two decades ago, studies that attempt to explore why individuals succeed, as appose to why they fail, reveal valuable success factors. Thus, researches and applications, like the one presented that take into consideration these principles and use diagnostic sensitive and patient-friendly technologies (such as virtual reality), could prove to be of particular interest.

Another interesting aspect for a future study comes from a more applied perspective. That is the rehabilitative use of environments like VIRDA-MS and their long-term educational effects. Therefore, simulations like ours could be used as customized assessment resources as well as individualized intervention programmes

[Attree et al. (2009)]. Such real-life environments could effectively integrate and/or nourish emerging (compensatory) strategies, a direction that would bring new insights to yet unexplored research fields. In addition, techniques like fMRI [Winn et al. (2006)] could provide valuable information about the brain activated areas in individuals with dyslexia during the demonstration of their memory strengths, memory weaknesses and compensatory strategies.

As far as the simulations and the VIRDA-MS per se are concerned, there also some proposals for future consideration. The modification of the application in order for the user to be able to have a more immersive and lifelike experience, that could possibly bring to light even more revealing findings about memory functions in dyslexia, seems particularly interesting. This could be achieved with the use of equipment such as a Head-Mounted-Display (HMD), data gloves or the introduction of avatars. Furthermore, it is worth examining the potential of simulations similar to the ones of VIRDA-MS, for the assessment and eventually rehabilitation of other dyslexia's symptoms such as laterality, time-spatial orientation, organization etc. The successful design and implementation of such virtual tasks could make applications like VIRDA-MS robust empirical (multicultural and multilingual/language-free) diagnostic tools for non-verbal skills.

In comparison to typical clinical approaches, there is a broad scientific recognition and need for naturalistic clinical tools with ecological validity [Parsons et al. (2009)]. We support that VR and its unique technological features can offer a breakthrough combination of innovative and effective human-centered and patient-friendly applications [Rose et al. (2005), Glantz et al. (2003), Rizzo et al. (2002)]. According to relevant researches in the field of clinical virtual applications (assessment and neurorehabilittion) [Rizzo et al. (2013), Fidopiastis et al. (2010), Winn et al. (2002)], these unique technological characteristics of VR provide a plethora of potentials for the use of VR applications as powerful clinical tools. These VR characteristics include immersion, presence, interaction, transduction and conceptual change. We suggest that they serve as development standards for the effective design and use of real-life virtual clinical applications for assessment/diagnosis and neurorehabilitation purposes.

In conclusion, taking into consideration that: a) dyslexia is a developmental condition that affects literature and non-literature skills (such as memory), b) dyslexia's memory inefficiency is fundamental, persistent and the most common, evident and sensitive indicator in both children and adult dyslexics, c) studies of successful dyslexic adults can lead to the identification of factors such as "compensatory strategies" that contribute to their success, d) the unique features of virtual environments and especially those regarding its realistic, intuitive, interactive, real time, adaptable, safe and most importantly multisensory character, we propose the use and future study of virtual environments, like the ones designed in our research: as a part of a sensitive memory screening tool for adults, as a part of an early identification test for children suspected for dyslexia, for the development of individual intervention programs, training and proficiency of compensatory memory strategies, in the screening, assessment and intervention in other non-literature skills affected in dyslexia such as organization [Becker et al.(2005), Levin (1990)], concentration/attention [Knivsberg and Andreassen (2008), Willcutt and Pennington (2000)], motor skills [Yang and Bi (2011), Savage (2004), Nicolson and Fawcett

(1994)], laterality [Helland et al. (2011), Iliadou et al. (2010), Annett (1996)], and in the screening, assessment and intervention in other special populations whose symptomatology includes memory deficits as in the cases of dementia, Alzheimer's disease, Parkinson's disease, traumatic brain injury, stroke, mental retardation.

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Appendix

The after task VIRDA-MS Questionnaire

The “VIRDA-MS Questionnaire” was administrated individually to each of the participants after the completion of the memory tasks and their personal interview. The questionnaire is short and attempts to reflect the students’ opinions regarding certain quality features of the virtual environments, their virtual experience and the application per se. Moreover, there was a special concern in the questionnaire’s dyslexia-friendly presentation and context [BDA (2013), Rello and Baeza-Yates (2012)]. In terms of presentation, the authors took into consideration several relevant features, such as text customization (i.e. font type and size), text and background colors, and text layout. Thus, black, 12point and sans serif fonts were used with light green and off-white background as well as non glossy paper. In the case of context, the writing style of the questions included short, simple and direct sentences. All the aforementioned features made a positive contribution towards the questionnaire's accessibility, readability and minimum writing requirements, as reported by both relevant literature and all the participants.

For the filling of the questionnaire, the following printed directions were given: Grade your responses by choosing a number from 1 to 5. By answering 1 you "strongly disagree", whereas by answering 5 you "strongly agree".

Q1 The quality of the presented images was very good.
Q2 The quality of the sound was very good.
Q3 The appearing objects were real-life looking.
Q4 It was easy to recognize the presented objects.
Q5 I was able to navigate very easy.
Q6 I felt like I was in an environment, rather than watching a series of images.
Q7 The duration of the application was adequate.
Q5 I enjoyed using the application.