Memory Performance of Dyslexic Adults in Virtual Environments

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Abstract

The use of virtual reality technologies in the evaluation process of the dyslexia syndrome has yet to be explored and is a true challenge for the scientists involved. The goal of this study was to design specialized tasks with the use of virtual reality, as a screening process 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 individuals with dyslexia. Taking into consideration the realistic design of the specialized and targeted assessment tasks, the study's insight results and the recorded positive attitude of the participants, it seems that use of such virtual environments, like our VIRDA-MS, could mark a significant breakthrough in the assessment as well as the intervention process not only in the case of the dyslexia syndrome, but also in other special populations with memory difficulties, contributing to their better and overall understanding.

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1. Introduction

It has been over 100 years since the word ‘dyslexia’ was first used in 1887, by ophthalmologist Rudolf Berlin [1]. Since then, the quest for a valid definition was ensued by numerous attempts, resulting to as much as forty-three definitions, according to Hammill [2]. A well known working definition of dyslexia is described by Lyon and it is attributed to the collaboration of the Orton Dyslexia Society Research Committee and various nationwide Research Associations, scientists and clinical experts: “Dyslexia is one of several distinct learning
disabilities. It is a specific language-based disorder of constitutional origin characterized by difficulties in single word decoding, usually reflecting insufficient phonological processing. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalized developmental disability or sensory impairment. Dyslexia is manifest by variable difficulty with different forms of language, often including, in addition to problems with reading, a conspicuous problem with acquiring proficiency in writing and spelling” [3].

Although the majority of existing dyslexia definitions reflect the common understanding that dyslexia mostly affects an individual’s reading, writing, and spelling skills, its conceptualization as a childhood educational condition is nowadays considered to be rather narrow [4]. In the last few decades, the use of significant scientific as well as technological breakthroughs in the dyslexia research field (e.g., PET scans, MRI, fMRI, rCBF techniques) [5, 6, 7] have widen our academic perspective of the syndrome’s characteristics. Thus, difficulties in laterality (i.e., the preference shown for the left or right side of the body resulting to cerebral dominance), memory, organization, (fine and gross) motor, spatial and temporal orientation skills are also included in dyslexia’s wide symptom catalogue [1, 8, 9].

As far as the deficits of the memory system (short-term, long-term, and working memory) are concerned, their manifestations are so prominent in dyslexia’s profile, that they are considered to be both typical indicators of the syndrome’s existence, and reliable indicators for a positive diagnosis in a diagnostic battery [1, 4, 10]. However, and besides all 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. Moreover, 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 is quite limited in the case of adults with dyslexia [4, 10].

Information and Communications Technologies (ICT) and lately Virtual Reality (VR) technologies seem to be powerful tools both for detection, as well as for treatment of certain symptoms of dyslexia. ICT 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 [11].

Although ICT offer support in several fields concerning learning difficulties, and in our case dyslexia, there is very limited evidence, as far as the implementation of virtual reality technology is concerned, in learning disabilities generally, and in dyslexia in particular. Most of the few and recently published studies regarding VR and dyslexia focused visuospatial abilities [12, 13] and visual representations [14]. As far as the visuospatial abilities studies are concerned, Attree and associates have reported that adolescents with dyslexia exhibited superior visuospatial strengths in a virtual environment, than their non-dyslexic peers [13]. Their virtual environment represented a bungalow with four rooms and 25 household items inside them. The subjects had to navigate inside the virtual environment, find a certain object, count the rooms, and construct a plan of the virtual bungalow. The results of this study suggested VR’s contribution in educational intervention and assessment for dyslexic adolescents. Moreover, in 2006, Winn and associates studied visual representation in elementary pupils by using the ‘Virtual Puget Sound’, a virtual environment simulating complex ecological processes [14]. Authors found that although good readers had significant correlations among activation of brain areas during a visual memory task, dyslexic children used the simulation to construct spatial mental models as the good readers did.

Based on the powerful features of VR and the few, but significant findings on the usage of Virtual Environments (VEs) to dyslexic populations, the present 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. Method

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’ [3]) 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 an intervention approach, both for adults and children.

2.1. VIRDA-MS, the virtual environment

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™ 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. 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 (Fig. 1).

![Fig. 1. Snapshots from the virtual rooms with the short-term memory subtests (left: semantic, right: non-semantic)](image)

In the first simulation, six (6) groups that respectively comprised of four (4) to nine (9) semantic stimuli (objects) (Fig. 1, left) 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 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) (Fig. 1, right) 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. 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.

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) hierarchically 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 (Fig. 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 [15]. 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 hierarchically escalated.

Fig. 2. Snapshots from the virtual art gallery and its long-term memory subtests (left: non-semantic, right: semantic)

2.2. Procedure

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 (Fig. 1). This test consisted of two subtests, the first of which included six colored sequences of the three-dimensional (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 researcher in a special designed form.
Similarly, for the second memory test, namely the test of ‘Direct and Reversed Visual Sequences Recall’ (backwards digit span) was administrated. In this second memory test the student was 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 [10, 16]. 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 [17, 18]. 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.

Initially participants arrived at the 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. Finally, after the completion of the tests, all participants were requested to complete the short ‘VIRDA-MS Questionnaire’ in order to record their attitudes towards the tasks in the virtual environments.

2.3. Participants

The sample was provided by the student population of the University of Ioannina, Greece. Two student groups were formulated: the control group (students without dyslexia: three male and four female students), and the experimental group (students with dyslexia: four male and three female students). The participants in the experimental group were all previously diagnosed with dyslexia by official state facilities.

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’ [19], 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

The difference between the control and experimental groups was not significant for the non-semantic visual stimuli ($Z= -1.483, p=0.165$). 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 for the short-term memory.

3.2. 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

There was not found any significant difference for the long-term memory ($Z= -0.903, p=0.367$ for the non-semantic, and $Z= -1.209, p=0.227$ for the semantic stimuli visual stimuli). Students with dyslexia had similar overall performance to students without dyslexia in the test and subtests for the long-term memory.

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). It can be seen that 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.

‘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. Therefore, long sequences of information such as tax identification numbers, telephone numbers, and passwords is easier to be recalled when they are broken into small chunks.

Table 1. Memory strategies implemented by the two students groups

<table>
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<tr>
<th>Students with dyslexia (compensatory memory strategies)</th>
<th>Students without dyslexia (memory strategies)</th>
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<tbody>
<tr>
<td>Counting of items number</td>
<td>Counting of items number</td>
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<tr>
<td>Item grouping in pairs or triads</td>
<td>Item grouping in pairs or triads</td>
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<tr>
<td>Item grouping based on common characteristics (e.g., initial phonemes, semantically, utilitarian)</td>
<td>Item grouping based on common characteristics (e.g., initial letter)</td>
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<tr>
<td>Self-sequence repetition</td>
<td>Self-sequence repetition</td>
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<td>Eye-closing during self-sequence repetition</td>
<td>Eye-closing during self-sequence repetition</td>
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<td>Story creation</td>
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‘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 as the participants remained silent and did not subvocalize. Therefore, there was no verbal/auditory feedback while they implemented this strategy.

‘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. Conclusion

The purpose of this study was the investigation and identification of memory skills in undergraduate university students with dyslexia, through their interaction with specially designed virtual environments.

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. This group of studies (i.e., dyslexia and memory) focuses predominantly in children, whereas in the case of studies of dyslexia and virtual reality there has been a small number of reports regarding both adult and child populations.

As far as memory performance in adults with dyslexia is concerned, McLoughlin, Fitzgibbon and Young [4] 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 [4, 10]). Our results regarding the good performance of dyslexic participants in the visual memory tasks are in agreement with the aforementioned suggestions of McLoughlin, Fitzgibbon and Young.

In addition, Torgesen and Houck [20] support 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 [1, 4, 8]. 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, our dyslexics’ good performance finding could presumably be considered as a controversial result, given the fact that there are several documentations of dyslexics’ low scores in similar memory tasks [1,
4, 8, 10]. However, as McLoughlin, Fitzgibbon and Young 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’ [4]. Both our results as well as our recording of compensatory strategies (Table 1) demonstrated by the dyslexic participants, are consistent with McLoughlin, Fitzgibbon and Young’s findings. 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 [10, 21-24].

In reference to dyslexia and virtual reality studies, our results agree with those of Attree and associates [13] who found that dyslexic adolescents ‘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. [14] associating good performances in visual tasks involving dyslexics and virtual reality technologies. 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 [1, 4, 10].

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 [4].

Finally, 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 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, concentration, motor skills, laterality, 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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