Abstract

This study is a critical review of published scientific literature on the use of Virtual Reality and its applications in developmental dyslexia. The purpose of this research is to: (a) present a synthesis of the available empirical evidence, (b) identify the potential contribution of Virtual Environments (VEs) in the disorder’s screening, intervention, awareness process and assessment, and (c) define future research perspectives concerning the applications of VEs in this particular research field. The results show that the research in the field focuses on: (a) visuospatial skills, (b) nonverbal problem skills, (c) memory performance, and (d) awareness increase for dyslexia. The majority of the articles found are pilot or small-scale studies that can only provide indications on the VEs and their beneficial results, but can provide useful guidance for researchers, educators, practitioners and parents.

Keywords: virtual reality; dyslexia; problem solving; visuospatial abilities; response time; memory; awareness

1. Introduction

With a wide repertoire of manifestations and a mosaic of aetiological factors and causes, developmental dyslexia (hereafter referred to as dyslexia) is one of the most challenging and highly debated disorders. It is indicative that since 1887 and the first appearance of the term dyslexia, which derives from the Greek language and literally means “difficulty with words” [1, 2], by the ophthalmologist Rudolf Berlin [2], there has been a
continuous scientific quest for a valid and commonly accepted definition. As stated by Ramus et al. [3], dyslexia is often defined as a “discrepancy between reading ability and intelligence in children receiving adequate reading tuition” (p.841). Thus, dyslexia is considered to significantly and specifically impair reading ability of individuals who appear to be intelligent, motivated, and without sensory and educational deprivations [4, 5]. Today and besides the behavioral approach of the disorder’s definition, it is established that dyslexia has a neurobiological basis, and therefore its manifestations are both lifelong and persistent. These neurobiological breakthroughs have widened the previous notion of dyslexia as a childhood disorder of academic failure and reading impairment [3, 6, 7]. Its biological origins, along with advances in brain and neuroimaging techniques and the recent increase of public awareness, have raised considerable scientific interest for transdisciplinary research in dyslexia and new assessment and intervention methodologies [3, 6]. In this modern approach of dyslexia, the use of Information and Communication Technologies (ICT) is considered to be beneficial for the individuals with dyslexia [8], and awareness supportive for their families and teachers [9].

ICT promote collaboration and communication through various activities involving the collection, processing, storage and representation of data and information [10]. Their technological characteristics and pedagogical features render them as powerful and supporting tools in education [11]. Digital learning environments have been used since the 1970s mainly in the mainstream education. Nevertheless, it is only recently that their contribution in the area of special educational needs has been acknowledged [12], as there is an increased interest in all aspects inclusion of individuals with learning disabilities [8, 13], such as dyslexia. Providing safe and controlled environments, motivation, high level of interactivity, immediate feedback, as well as improvement of visual and memory skills [14], ICT support the effective learning of these individuals. Their implementations to the assessment [15] and intervention process (general strategic techniques, specific skills training, multisensory approaches) are significant in terms of an effective education and learning experience [16]. Moreover, ICT can provide support not only to the individuals with dyslexia, but also their families and educators by increasing their knowledge and understanding of the numerous challenges those individuals face in their everyday life [9].

Since Virtual Reality (VR) technologies first surfaced in the 1960s, their unique characteristics differentiated them from other information technologies, making them powerful educational tools [10, 17]. Blending a technological and conceptual approach, Mikropoulos and Strouboulis [18] propose the following definition: “Virtual Reality is a combination of high-end computing, human computer interfaces, graphics, sensor technology and networking which allows the user to become immersed in, interact and experience in real time a three-dimensional (3D) artificial environment representing realistic or other situations” (p.583).

In the last fifteen years there have been some remarkable technological and scientific advances in this area, making VR from a sophisticated toy and powerful educational mean, to a valuable assessment and intervention tool. Features such as 3D dynamic yet controllable environments, stimuli control, and behavioral documentation and quantification are important assets of VR technology and its clinical applications (assessment, intervention, and training) [19]. There are now numerous studies that support the use of VR applications in cognitive, psychological, and physical (motor and functional) disorders. The wide repertoire of such clinical applications ranges from specialized simulations for pain management [20, 21] to virtual environments for populations with cognitive impairments [22-24], special needs (e.g. autism) [25] as well as learning difficulties [26]. In the case of dyslexia, there are only a handful of studies that present virtual reality applications for the child and adult dyslexic population.

This article is a literature review. Its purpose is to examine relevant empirical studies, demonstrate the effectiveness of the proposed applications in dyslexia assessment, intervention and awareness, recognize their potential (positive) impact in the aforementioned domains, contribute towards an understanding of VR applications as powerful and sensitive clinical and research tools, and promote further research in this particular research field.

2. Method

The research axes of this study are the investigation of the:

• uses of Virtual Reality technologies in dyslexia research
particular application field as well as the features of the implemented virtual environments
outcomes, effectiveness, improvements and proposed future research work.

For the aim of this study we respectfully combined the research model followed by Mikropoulos and Natsis [10] and the methodology proposed by Kitchenham [27] and Khan et al. [28]. Thus, there are three consecutive stages in our study, which include the following activities:
Stage 1: Planning of the study
Activity 1.1: Study need and rational
Activity 1.2: Methodology
Stage 2: Conduction of the study
Activity 2.1: Research identification
Activity 2.2: Inclusion criteria
Activity 2.3: Quality assessment
Activity 2.4: Data extraction
Activity 2.5: Data synthesis
Stage 3: Study report
Activity 3.1: Presentation of the study’s results.

2.1. Planning and conducting the study

This study includes peer-reviewed empirical studies written in English and published as full-length articles in scientific journals and proceedings of international conferences during the last decade, 2003-2013. It should be noted that although the chronological beginning of our research is placed in 2003, the first article meeting our criteria was published in 2005. Furthermore, our search did not yield any empirical studies from symposia, workshops, or books, fulfilling our inclusion criteria, as presented below.

Firstly, as suggested by de Vet et al. [29] and Kitchenham [27], the following research questions were formed and placed in order to examine the study field of VR applications in dyslexia:

Question 1: What virtual environments/applications have been used in dyslexia research? What are their aims and goals?

Question 2: Is virtual reality an effective clinical tool for increasing and improving awareness in the case of dyslexia? What do studies show?

Question 3: What are the unique features of virtual reality that make these technologies valuable and differentiate them from traditional (e.g. paper-and-pencil) processes and other technologies? What is their impact in our current understanding and future research?

Thus, in our attempt to answer the aforementioned research questions, we identified relevant literature through a search in electronic databases of academic resources, organizations and publishers, including ERIC, EBSCOhost, ProQuest, JSTOR, ACM DL DIGITAL LIBRARY, EJC (OhioLINK), ScienceDirect (SciVerse), PubMed (NCBI), Taylor & Francis Online, IEEE, WilsonWeb, Elsevier, Mary Ann Liebert, SpringerLink, and Wiley Interscience. The keywords originally used for our search were “dyslexia AND virtual reality”, followed by “dyslexia AND virtual environments”. In addition, we searched for studies that were cited in the papers we read. However, we excluded (unpublished) theses [30, 31]. Both empirical and pilot studies were included; as well as articles that clearly refer to individuals (adults and children) with dyslexia (i.e. assessment, intervention, training) and applications that have a direct relation to dyslexia (e.g. dyslexia awareness). We also included articles published in conference proceedings, as relevant literature [32] supports that they show no practical, statistical and methodological differences from articles published in journals.

On the other hand, short papers presented at conferences, symposia and workshops did not meet our criteria. Moreover, articles regarding simulations for populations with special needs, learning difficulties, and reading disorders were also not included as the characteristics although appear to be to some degree similar to those of individuals with dyslexia there are significant neurobiological, cognitive and aetiological incompatibilities. Furthermore, virtual classrooms/schools and virtual learning environments [33] were excluded as they are
differentiated from virtual environments and usually refer to technologies different from virtual reality (e.g. e-
learning, on-line platforms, CMSs, LMSs) [10]. Only seven (7) articles, published within the last decade (2003-
2013), met our criteria and were therefore included in our study. Six (6) of the articles were published in journals
[34-39] and one (1) was presented and published in an international conference’s proceedings [40]. The six journal
articles are respectively published in six different computer and/or education related journals and are
indexing/abstracting in databases such as ACM DL DIGITAL LIBRARY, ERIC, MEDLINE and EBSCOhost. The
seventh article is also published in computer science related journal of conference proceedings, and it is
indexing/abstracting in ScienceDirect (SciVerse), where the reader has also free full text access. The impact factor,
whose importance is strongly debated by some researchers [41, 42], ranged for all seven journals between 0.444
and 2.178.

Finally, as many authors state in some of the most recent and relevant literature [19, 43-45], multisensory
interaction, intuitive interactivity, immersion and presence are the key features of VR. These features are reported
to contribute to VR’s effectiveness and therefore its use in applications for (clinical) assessment, intervention and
awareness. Thus, it is the aforementioned features that we attempt to identify and investigate in the reviewed
studies.

3. Results

All seven included studies are experimental studies with references to the inclusion of control groups. The
relevant references (column 1), along with a short description (column 2) and the (clinical) direction of each study
(column 3) are presented in Table 1.

In respect to the limited results of our research (i.e. only seven relevant studies were identified), we attempt in
this section to answer, and not generalize, the specific three research questions previously stated.

Question 1: What virtual environments/applications have been used in dyslexia research? What are their aims and
goals?

As various categorization criteria could be employed, in a clinical and psychocognitive approach, there are
three broader areas that the presented studies aim: (i) assessment, (ii) intervention, and (iii) awareness. There are
three studies that focus on performance and skills assessment of individuals with dyslexia.

In particular, Sigmundsson [39] assesses and compares the response time of young adult dyslexic drivers to
non-dyslexic drivers with the use of a car simulator. Moreover, Attree, Turner and Cowell [35] constructed a
virtual bungalow for the identification of visuospatial skills in pupils with dyslexia. In the study by Kalyvioti and
Mikropoulos [40], six virtual environments were used for the screening of memory skills in undergraduate students
with dyslexia diagnosis. As far as the use of VR in intervention is concerned, Winn et al. [38] used for two weeks
an interactive 3D simulation of the physical oceanography of Puget Sound (VPS), in order to investigate the
contribution of such simulations in the construction of spatial metal models. This particular study was part of a
second research, by Berninger et al. [36]. More specifically, in this second larger research of the effects of
instruction on the phonological and writing skills of students with dyslexia, Berninger and colleagues [36] report
the use of VPS for the development of nonverbal representations for problem solving. The last two studies were
conducted by Passig [34] and his colleagues [37] and regard the raise of dyslexia awareness. Thus, in regards to the
2008 study, the authors used ten immersive virtual environments in order to help parents with dyslexic children
understand, and therefore increase their awareness, the cognitive challenges that children with dyslexia face.
Following the same rational and targeting this time teachers, ten virtual environments where also administered in
the 2011 study, which aimed at the raise of dyslexia awareness in educators.

It is worth mentioning that, although all seven studies are dyslexia relevant, five of them involve dyslexic
individuals per se. Moreover, as far as these five studies are concerned, only two of them, Sigmundsson [39] and
Kalyvioti and Mikropoulos [40], involve young adult dyslexic population. We believe that the age targeted
population, mainly children (school students), as well as the relatively small numbers of participants, are indicative
of: (a) the still prevailing notion that dyslexia is a children’s disorder, (b) that it mainly impairs academic skills, (c)
the increase in public awareness about the disorder, (d) the current rational of early diagnosis and treatment, (e) the
lack of adequate clinical tools for adults with dyslexia, (f) the development and use of compensatory strategies by
successful dyslexic adults, who therefore escape diagnosis, and (g) the stigma that a dyslexia diagnosis can place.

Question 2: Is virtual reality an effective clinical tool for increasing and improving awareness in the case of dyslexia? What do the studies show?

Table 1. Reviewed articles, study area and type (A: Assessment; I: Intervention; T: Training; In/Aw: Informative/Awareness)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Article description</th>
<th>Study area</th>
</tr>
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<tbody>
<tr>
<td>Sigmundsson (2005)</td>
<td>This study compares the response time of drivers with and without dyslexia with the use of a car simulator.</td>
<td>A</td>
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<tr>
<td>Winn et al. (2006)</td>
<td>This article reports the effectiveness of a computer-based, interactive, 3D ocean simulation for the accurate and useful construction of spatial and metal models of complex natural phenomena by dyslexic elementary students. It is part of a larger research of the effects of phonological and writing intervention in pupils with dyslexia (Berninger et al., 2008).</td>
<td>I, T</td>
</tr>
<tr>
<td>Berninger et al. (2008)</td>
<td>The purpose of this paper is twofold as it aims towards the evaluation of the effectiveness of: first, writing intervention for students with dyslexia and second, language or nonverbal science problem treatment solving (VR simulation) for dyslexic students.</td>
<td>I, T</td>
</tr>
<tr>
<td>Passig, Eden and Rosenbaum, (2008)</td>
<td>The purpose of this study is the development of VR immersive 3D worlds for the improvement of awareness of parents with dyslexic children.</td>
<td>I, In/Aw</td>
</tr>
<tr>
<td>Attree, Turner and Cowell (2009)</td>
<td>This paper describes the implementation of a computer-generated virtual environment test for the identification of superior visuospatial skills of adolescents with dyslexia.</td>
<td>A</td>
</tr>
<tr>
<td>Passig (2011)</td>
<td>This paper investigates the possible impact of VR on educators’ understanding of the needs and cognitive experiences of students with dyslexia.</td>
<td>T, In/Aw</td>
</tr>
<tr>
<td>Kalyvioti and Mikropoulos (2012)</td>
<td>This paper reports on a pilot study, which presents a novel application of virtual technology for the investigation of memory difficulties of undergraduate dyslexic students.</td>
<td>A</td>
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An interesting finding, as far as the use and effectiveness of the implemented virtual environments is concerned, is that almost all of the included studies report positive results. Thus, these particular results are in agreement with similar positive findings identified in numerous studies, where virtual environments have been usefully applied for clinical assessment purposes, cognitive neurorehabilitation and in clinical psychology domains [43, 45-50]. However, it should be noted that though the few, there are some studies with mixed, inconclusive [51] or even negative results [45]. In the case of our research, one of the included articles, the Kalyvioti and Mikropoulos [40] study, presented inconclusive findings, as both the control and experimental group had similar performance scores. We believe that the particular results are attributed to some indicative clinical and research factors such as: the dyslexic participants were successful adults, they had developed and mastered compensatory strategies, and there is a lack of test batteries for adult dyslexics who often escape of a positive diagnosis. Moreover, as it is generally reported, the unique features of VR have in general a positive impact in participants’ performance. Therefore, a performance comparison between virtual memory tasks and more traditional (e.g. paper-and-pencil) memory tests would be beneficial. In addition, the implementation of these VR memory tasks in younger school-aged individuals would highlight the memory difficulties experienced by the dyslexic population and reinforce the use of VR as a powerful assessment tool.

We believe that the impact of these observations is trifoul. Firstly, they underline the need for further empirical
studies, a demand also vividly pointed out by all the authors of the seven studies. Secondly, they reflect the common perception that dyslexia is an academic disorder. Therefore, there is a research focus on its language aspect, with very few studies regarding the non-verbal characteristics (e.g. memory, lateralization, time and space orientation). This reflects to the small number of VR dyslexia studies, as the technology per se is more visual and nonverbal. Thirdly, the aforementioned results highlight the unique technological features of VR and its applications, which we present next. Finally, it is worth mentioning, that it is those nonverbal dyslexia characteristics that can serve as warning signs in early dyslexia screening, even in pre-school ages. In that case, this would provide valuable time for therapists and effective individualized early intervention program for individuals with dyslexia. Thus, further research and exploration of the uses of VR technologies in this field could provide useful insights for individuals with dyslexia, parents, educators, therapists and researchers.

**Question 3:** What are the unique features of virtual reality that make these technologies valuable and differentiate them from traditional (e.g. paper-and-pencil) processes and other technologies? What is their impact in our current understanding and future research?

Depending on the research approach, there can be five powerful and unique features of virtual reality that contribute to the current acknowledgement of these technologies as innovative assessment and treatment tools. All seven studies make direct or indirect references to the important role of immersion, presence, interaction, transduction and conceptual change. Starting from the latter, conceptual change refers to the user’s creation or change of concepts. Although relative references are often reported in a more educational context (e.g. science learning), where this particular VR feature is empirically acknowledged, its effectiveness is generally applicable in all aspects and uses of VR [52]. In our case, we believe that conceptual change affects uniquely the outcomes of all seven researches, and it is most indicative in the case of the dyslexia awareness studies. Moreover, as far as immersion is concerned, Winn et al. (2002) report that immersion contributes towards conception development by increasing the user’s presence, i.e. “the sense of being there”. It is worth mentioning, that our research identified only two applications involving immersive VR [34, 37], produced by a combination of computer-generated simulations and the use of Head Mounted Displays (HMDs). The remaining simulations use the more common non-immersive VR systems.

Immersion and presence make the VR experience more engaging, increase user’s receptiveness to the introduced stimuli, and contribute towards conceptual changes. The impact of these features was documented in Kalyvioti and Mikropoulos [40] with the posttest administration of their questionnaire, which captured the positive attitudes of all participants towards the applied VR environments. Finally, and in the same direction, interaction, one of the “I’s” of VR (along with Immersion and Imagination), enables the user to respond to the virtual stimuli, send his/her feedback to the system and control the environment [53]. This VR characteristic (interaction), as well as the feature of transduction, i.e. making virtual stimuli sensory accessible to the user [52], offer a complete and real life virtual experience for the participants and a plethora of data for the researchers, as it is witnessed in the MRI findings of Berninger et al. [36] and Winn et al. [38].

Thus, the aforementioned characteristics of VR allow the introduced 3D environments to be dynamic, multisensory, precise, and yet safely controlled. As far as the safety a virtual environment can provide, it is a feature of particular significance in certain studies, with the most indicative example the car simulation of Sigmundsson [39]. In addition, VR environments offer a combination of naturalistic and familiar input, which along with advanced recording and quantifying methods of users’ performances, provides valuable ecological information. All these features support the rationale for the development of innovative and cost-effective VR clinical applications, as assessment and intervention tools, in different neurocognitive, psychological and educational domains [43, 45]. However, it should be underlined that in order to acknowledge the ecological advantages of the effective use of such applications versus the traditional and typical clinical methods, further empirical, large-scale, longitudinal and follow up studies are required.

4. Conclusions

As literature suggests, virtual reality is considered to be a promising tool in numerous and different areas of therapy and intervention) [54, 55]. Our findings agree with Rizzo et al. [19] and Parsons et al. [45] that VR
applications can be valuable clinical tools for adult and child population with neurocognitive and neuropsychological impairments. In matters of dyslexia, a neurodevelopmental reading disorder, our research provides the few existing, yet significant indications that the aforementioned findings also apply in our case. Thus, this study is a presentation of empirical research on applications of virtual reality in dyslexia. To the best of our knowledge, a thorough research was conducted in a total of fourteen (14) different electronic databases of academic resources, organizations and publishers. This research, when combined with specific search criteria, brought to light only seven studies. Thus, taking into consideration the limitations derived from the small number of found studies, it is about an exploration effort for dyslexia relevant studies. Our aim is to provide insights of the current research status in dyslexia and VR, identify the unique features of VR technologies, suggest the rational that serves as a basis for the effective use of these virtual applications in dyslexia research, as well as highlight future research perspectives.

VR features along with the current scientific recognition of the need for real life representative clinical tools, offer a unique combination of innovative and effective human/patient-centered applications [50, 55-57]. Traditional approaches, e.g. typical paper-and-pencil diagnostic methods have been reported to have a limited ecological validity, as this type of tests has a constricted everyday relevance [45]. After all, identifying capabilities and weaknesses, as well as coping and functioning in real world tasks is what makes a clinical assessment complete and an intervention successful. Moreover, and from a different aspect, for non-dyslexic individuals, imagining or trying to understand what these difficulties are and how they affect, both cognitively and psychologically, dyslexics is a rather demanding task. VR technologies can have a significant positive impact in helping those who engage with these individuals (e.g., parents, educators, therapists, clinicians) to experience firsthand the challenges dyslexics face inside and outside of an academic context. Thus, as relevant studies report [31, 34, 37], such applications have the unique ability to effectively increase knowledge and raise awareness of the virtual explorers.

Besides the potentials of VR applications as powerful clinical and awareness tools, it is essential to identify and understand those technological features that are the basis for the aforementioned rational. Our study, as well as other relevant researches in the field of clinical virtual applications (assessment and neurorehabilitation) [19, 52, 58], suggests that these unique technological characteristics of VR include: immersion, presence, interaction, transduction and conceptual change. Thus, it is that exact and real life presentations that take place in the dynamic, multisensory, controlled and safe virtual environments that evidently provide successful interaction and performance recording in several clinical and broader domains. It is worth mentioning, that only two of the included studies [34, 37] used immersive systems. The other five applications [35, 36, 38-40] used desktop systems with the participants being able to navigate and interact in the 3D virtual environments. In the case of these applications, and as Rizzo and colleagues state [19], although they are less immersive, nevertheless they are still considered to be virtual reality simulations and contribute to the sense of presence.

Finally, taking into consideration the technological advances and the decrease in systems cost, we support the need of systematic, longitudinal and larger scale studies for the implementation of virtual environments in both adult and child population with dyslexia. With the prospect of positive cost-effective outcomes [58], such studies could provide empirical and strong evidence of the beneficial use of virtual environments, as valuable and powerful clinical tools for screening, assessment, individual intervention programming and awareness means for the broader community. Nevertheless, as Rizzo et al. [19] highlight we also would like to suggest that given the fact of the diversity of each disorder and individual, as well as the relatively unpredictable and sensitive human factor/involvement, even the most state of the art virtual applications should be regarded as an extension of the skills of capable clinicians and be “administered within the context of appropriate care via a thoughtful professional appreciation of the complexity and impact of this behavioral health challenge” (p.18).

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