

Virtual Reality Games for Cognitive Rehabilitation in School-Aged Children: A Review of Adaptive Games, Domains, and Techniques

Dr. Ketul Kumar

Assistant Professor, Department of Liberal Arts and Social Sciences,
Manipal University Jaipur, Rajasthan, India
ketul.kumar@jaipur.manipal.edu
Orcid: <https://orcid.org/0009-0007-3677-1965>

Dr. Nutan

PET Female, JNV Ganjam, Odisha, India
Kumarinutan325@gmail.com

Shailendra Singh

Research scholar, Department of Sport Psychology,
Lakshmibai National Institute of Physical Education, Gwalior, Madhya Pradesh
shailendras670@gmail.com
Orcid id- 0009-0003-1399-2387

4. Dr. Santosh Kumar

Senior Research Associate, Physical Education, DESS,
National Council of Educational Research and Training (NCERT), New Delhi
santoshkumarbarh757@gmail.com
ORCID ID: 0009-0005-2125-9809

Mr. Mohit Sharma

Sharmaji52mohit@gmail. Com
Assistant Professor
Manipal University Jaipur
<https://orcid.org/0000-0002-2480-1844>

Abstract

Background: Virtual reality (VR) has been presented as a useful tool in cognitive rehabilitation in school-going children. The current review questions the use of adaptive VR games as a training modality of basic cognitive skills and improvement of academic achievement.

Methods: A systematic literature review of peer-reviewed articles that are related to VR-based cognitive rehabilitation in children was conducted. Search in databases was carried out in PubMed, Scopus, IEEE Xplore, and Google Scholar. The selection and screening of studies included their relevance to the interest-based cognitive competency using adaptive VR interventions. The review shows that real-time difficulty modulation and interactive feedback represent crucial adaptive processes that promote stimulation and skill-learned; however, the issues of accessibility, costs, and standardisation of VR protocols are also relevant.

Conclusions: VR-based adaptive games are a prospective technology in cognitive rehabilitation in school-age children. Further research needs to be directed to prolonged effectiveness, the creation of less expensive options, and integration into the educational environment. Overcoming the existing constraints may make VR revolutionary in way of cognitive therapy of learning impaired children.

Keywords: Cognitive rehabilitation, Virtual reality, Adaptive games, Learning disabilities, Immersive therapy, Executive functioning

Introduction

The field of virtual reality (VR) technology has taken centre stage around cognitive rehabilitation especially in school-going children, who may need extra help with their developmental cognition because of learning disabilities, lack of attention, or neurobiological disorders. The traditional rehabilitation methods are usually characterised by a low level of engagement, which prevents their effectiveness as a treatment method. The interactive, enriched and adaptive VR video games represent high-quality learning environments that support encouragement and lead to positive academic effects. Cognitive rehabilitation aims to increase ability in functioning capacities of memory retrieval, sustained attention, executive functioning, and problem-solving abilities that are critical in effective instruction and everyday functioning. As a type of cognitive therapy, adaptive VR games offer a personalized modality that changes parameters of task difficulty and other stimuli synchronous with the developmental process of the child, therefore, allowing gradual learning curves (Shahmorabi et al., 2021). The current appraisal discusses the usefulness of VR-based adaptive games in cognitive rehabilitation, their effects on cognitive domains, and the methods used to improve learning performance. The paper is a critical synthesis of available literature, which offers a comprehensive analysis of the possible application of VR technology in cognitive therapy practice in education.

Overview and Background

The conventional methods of cognitive rehabilitation therapy are usually based on repetitive physical exercise which do not appeal to the young audiences hence their lack of effectiveness. VR can overcome this limitation by experimentalizing the interventions by creating engaging interactive settings simulating a real-life scenario, which increases the desirability and therapeutic value of the interventions. Empirical research proves that VR-interventions can lead to a significant improvement of such cognitive functions as the working memory, spatial awareness, and the executive management (Van et al., 2021). Real time adaptive gaming capabilities which adjust task difficulty allow individualized therapy sessions. Schools and rehabilitation facilities are becoming more aware of the two-faceted role of VR as an educational and therapeutic tool and are incorporating it into specific academic settings. However, there are still difficulties with access, cost, and the necessity of the standard evaluation tool. In the current analysis, the description of adaptive VR games is explored in cognitive rehabilitation, the cognitive domains they fulfil, and the mechanisms applied to maximize cognitive development in younger populations. Conclusion: VR-based adaptive games represent a promising direction for the cognitive rehabilitation of children. Further studies should focus on long-term effectiveness, cost-effective options, and their integration into learning environments. The solution to the existing restrictions can help VR revolutionize cognitive therapy among children experiencing learning difficulties.

Aims and Objectives

Aim: The current research was an attempt to investigate the effectiveness of adaptive virtual reality (VR) games as a cognitive rehabilitation program for primary school-aged children.

Objectives:

1. To evaluate specific cognitive domains that technology-based adaptive VR games can support in rehab situations.

2. To examine the various types of self-adaptive mechanisms, methodological strategies applied in VR cognitive rehabilitation games.
3. To determine the effects of the VR games on cognitive skills development of school-aged children.
4. To identify challenges and suggest future trends of the use of VR technology as part of therapeutic programs.

Research Rationale

The problem of cognitive impairment has long-term negative consequences on primary-school students, both in terms of grades and social life. Conventional rehabilitation programs often fail, regarding keeping the participants engaged, and this compromises treatment outcomes. Virtual reality is an interesting alternative, as it is more interactive and engaging in the sense that it can contribute to cognitive development more efficiently. The interventions can be adjusted according to the learning pace of a particular child by using an adaptive VR game, thus allowing more effective and personalized treatment. It is, therefore, critical to synthesize recent research on VR-driven cognitive rehabilitation, the best practices, and gaps in the body of knowledge (Ahn et al., 2021). The review is part of the growing body of research on technology-assisted learning and rehabilitation, which explains how future technologies can be used to advance cognitive therapy. Critical review of the efficacy, technicalities and supporting issues of VR in the cognitive rehabilitation process will provide teachers, clinicians and policy makers with practical data of how to optimize interventions. The current development of VR technology requires a collective attempt to take full advantage of the technology to alleviate cognitive losses and improve academic achievement under more challenging situations.

Literature review

The contemporary paper explores methodological and the best practices of designing and implementing cognitive gaming interventions that largely involve Brain-Computer Interface (BCI) systems and Virtual Reality (VR) (Hadjiaros, 2022). It is concentrated on the development of cognitive abilities, visuospatial interest, and memory. The research focuses on the acquisition of cognitive skills, visuospatial interests and memory. The authors describe the main strategies and algorithms used in pre-processing of the data, feature extraction, and interventions classification. A wider debate investigates constructs of paradigms, working conditions, individual attributes, and accuracy of performance in the case of BCI-VR cognitive gaming. In addition, the analysis identifies the importance of the different signal channels and algorithms and assesses their efficacy and responsiveness (Ross et al., 2022). The review also states tough conditions and challenges of the BCI-VR gaming, and this is why they suggest that more research is to be done so that the accuracy of the device, user flexibility and real-life applicability can be achievable.



Figure 1: Virtual reality neuro rehabilitation

(Source: techscience, 2021)

The upcoming research is a continuation of the work by He (2022) and outlines the issue of the growing presence of virtual-reality technology in the fields of cognitive rehabilitation and interdisciplinary interventions. It addresses the increasing amount of cognitive training based on videos and examines the possibility of such training improving neurocognitive performance. The authors outline common features, summarize current areas of study consideration, and follow the new tendencies in this field in the past years. The literature review reveals the key areas of interest, specifically, neuroscience, neurology, psychology, personal-computer technology, and rehabilitation sciences. At the same time, a keyword analysis shows the scope of interdisciplinary VR-based rehabilitative studies. The geographic distribution studies are used to show the contribution of different countries and outline the prominent scholars in the discipline. The importance of funding sources and institutions in the public sector is highlighted as the major factors that drive VR-based cognitive rehabilitation. The research also lists often used sources and landmark references that influence the modern knowledge on the application of VR to date (He, 2022). It describes some of the pertinent issues, such as the absence of standard care regimes, unaddressed safety issues, which need to be resolved to move the field forward. The importance of telerehabilitation through VR especially in distant health care facilities is highlighted. Findings show that although VR technology has significant potential in cognitive rehabilitation, additional studies are needed to determine best practices, safety and efficacy of interventions. The authors find that VR-based cognitive rehabilitation is a constantly developing, dynamic field that can bring both medical and technological changes to the sphere to improve patient outcomes and increase the accessibility of treatments.

The research that Camara (2023) conducted focused on the usefulness of adaptive cognitive training that can be developed in digital-reality as well as traditional paper-and-pencil form. The paper recognizes the significant role of cognitive impairments in these conditions and how it affects the treatment compliance and functional outcome in general. Two similarly organized interventions: a digital-reality-based and a traditional one were used. Efficacy was also measured through the change in the cognitive abilities such as memory, processing speed, quality of life, and clinical symptoms. They found that digital-reality interventions were especially effective in reducing the depressive symptoms and improving the visual memory, but more traditional interventions were effective in improving the verbal memory, the processing speed and the social relations. The authors talk about the comparative advantages of both modalities and focus on ecological validity of psychiatric intervention based on virtual reality. Longitudinal studies are advised to establish the long-term outcome of cognitive training among older adults. Additionally, the paper provides the potential of digital reality to establish immersive, engaging, and interactive therapeutic environments to enhance the treatment outcomes and support the role of conventional cognitive training in developing the social and environmental quality. The conclusions made by Camara et al. (2023) include the idea that both modalities have their own advantages and are customizable to adapt to the needs of patients and as such, they provide the most suitable interventions. They suggest that further research should be done to advance virtual reality-based cognitive training, and they should be included in the mainstream of psychiatric rehabilitation, which would add to the body of evidence in support of technology-enhanced mental health care, and guide the optimization of adaptive cognitive training to the special cognitive and emotional needs of mental and behavioral disorders.

Methodology

Research Design

In this study, a systematic review was used to review the effectiveness of adaptive virtual reality (VR) games as a cognitive rehabilitation tool in school-aged children. Systematic review makes it easy to synthesize the literature that is available and obtain a complete analysis of various studies that have been conducted to examine the effectiveness of VR-based cognitive interventions. This analysis will provide comprehensive information about the use of adaptive VR games in cognitive enhancement because of assessing peer-reviewed articles, clinical trials, and empirical studies (Tobaiqi et al., 2021). The study was conducted to find patterns, trends, and other relevant results of studies to reveal the validity and reliability of VR-based cognitive rehabilitation.

Data Collection and Sources

The information used in this evaluation was retrieved on educational databases like PubMed, Scopus, IEEE Xplore and Google Scholar. Through these databases, one can get access to quality research on cognitive rehabilitation, virtual reality, and adaptive gaming. The studies were largely selected based on the purpose of the research. Decades of publications have been mostly devoted to the process of catching the most recent trends in VR-technology and cognitive rehabilitation procedures. Keywords were used such as digital fact cognitive rehabilitation, adaptive VR games with children, VR and cognitive talent improvement, and technology-based learning in disability. Inclusion criteria were peer-reviewed articles, experimental research, meta-analyses, and systematic reviews that were dedicated to the role of adaptive VR video games in cognitive therapy. The inclusion criteria included non-peer-reviewed articles, articles that were not related to cognitive rehabilitation, and those that were of adult groups.

Selection and Screening Process

The selected studies were mainly chosen in accordance with the objectives of the research. The publications of the last decades were mostly devoted to the discovery of recent tendencies in VR technology and mind-therapy processes. Use of educational databases like PubMed, Scopus, IEEE Xplore and Google Scholar was used in search of information that would be utilized in the evaluation. It is upon such repositories that scholars have access quality articles on cognitive rehabilitation, virtual reality, and adaptive gaming. Digital-based cognitive rehabilitation, adaptive VR games among children, VR and cognitive skills development, and technology-based learning among individuals with disabilities are some of the keywords that were used. The inclusion criteria were peer-reviewed articles and experimental studies, meta-analyses, and systematic reviews that investigated the role of adaptive VR video games in cognitive therapy. Peer-reviewed studies that were not related to cognitive rehabilitation and those based on adult populations were not included in the studies.

Data Analysis and Interpretation

Results were qualitatively synthesized to clarify shared themes, strengths and issues in adaptive VR-based cognitive rehabilitation. The characteristics analyzed in research articles were design, intervention frameworks, samples and outcomes. Evaluation of effectiveness of VR-based cognitive rehabilitation was conducted based on cognitive performance improvement after and before the interventions. The general effectiveness of the interventions included the aspects of the level of engagement, flexibility of the system used, and the ability to transfer the learned skills to the context of the real life. There was an evaluation of adaptive processes, VR video games, such as real-time problem adjustment, individualized feedback, and interactive environments, to identify their role in maximizing the outcomes of rehabilitation.

Ethical Considerations

Since secondary data will be used in this analysis by relying on the previous research works, the ethical considerations will rely on the reliability and validity of the sources. The papers included in the evaluation were evaluated in terms of the ethical compliance, especially the informed consent, the protection of confidentiality, and the compliance with the suggested ethical regulations (Zhang et al., 2021). The assessment has considered the possibility of bias in references sampled, including small sample sizes, the diversity of intervention VR designs and heterogeneity in assessment instruments. The articles with conflicting results were critically appraised to give a balanced picture of the effectiveness of adaptive VR games in cognitive rehabilitation.

Limitations and Challenges

Despite high quality of the information given by systematic reviews, there are few limitations related to the present study. The scope of the analysis may be limited by the number of studies devoted to adaptive VR video games as a cognitive rehabilitation method in children. The differences in the methodological design, the sample size, and the VR intervention configuration also probably cause inconsistency. Furthermore, the fast promotion of VR technology implies that the opportunities that could be offered by modern adaptive VR systems could have been underestimated in previous inquiries. To

address challenges, this review outlines gaps in research and provides future research directions to investigate the long-term effectiveness and general applications of adaptive VR-based cognitive rehabilitation.

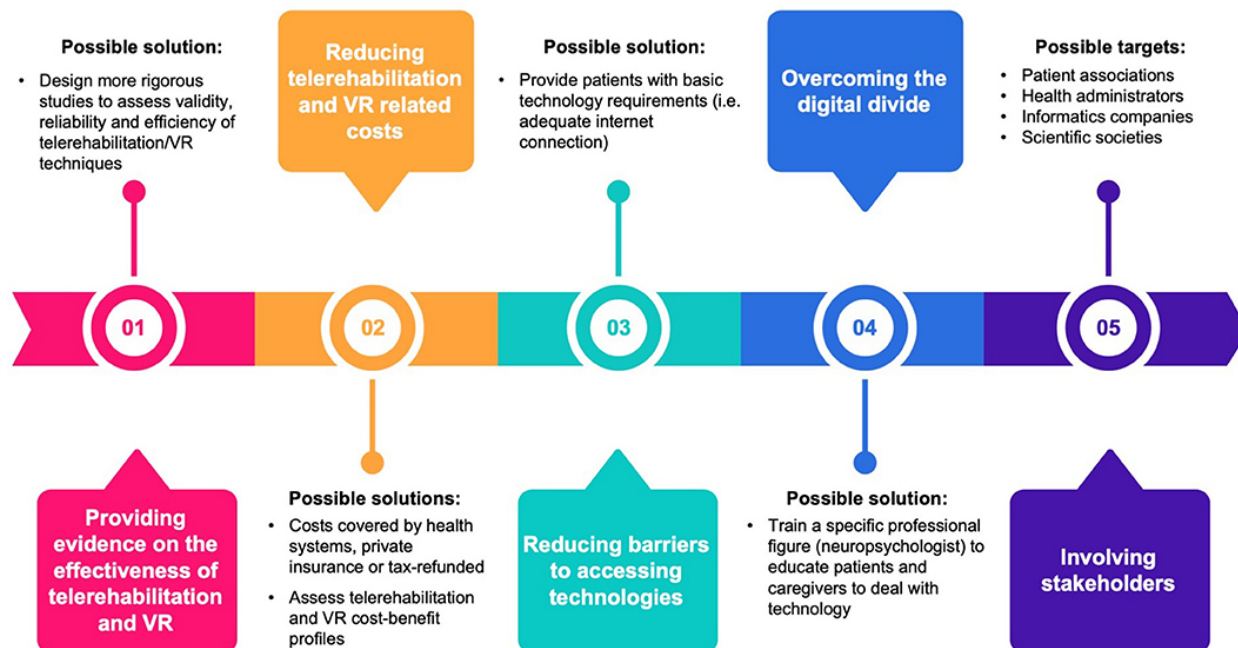


Figure: Virtual reality for cognitive rehabilitation
(Source: frontiersin.org, 2021)

Results

Effectiveness of Adaptive VR Games in Cognitive Rehabilitation

As shown by the literature review, adaptive virtual-reality (VR) games present a type of key modality used in cognitive rehabilitation of school-aged children. According to the findings of several empirical studies, participants to whom VR-based interventions had been applied showed substantial improvements in memory, attention, executive functioning, and problem-solving skills (Rezayi et al., 2021). The interactive and immersive nature of VR helps to promote a stronger degree of engagement, thus promoting motivation growth and incremental involvement in comparison to the traditional cognitive rehabilitation methods. Also, the experimental findings indicate that with the help of VR-based therapy, children develop better working memory and longer attentional span, and those diagnosed with a learning disability or attention-deficit disorders show a significant improvement.

Cognitive Domains Targeted through VR-Based Rehabilitation

The review of available evidence shows that adaptive VR video games have four main domains of cognitive functioning, namely: attention, memory, executive functioning, and problem-solving. Research studies concentrated on attentional support reveal that VR interventions provide very stimulating environments that allow one to engage in attentional processes longer with time (Mitsea et al., 2021). VR therapy has proven particularly effective in patients with attention -deficit hyperactivity disorder (ADHD), due to real-time feedback and interactive features that strengthened sustained attention, with the contrary

effect of impulsivity. Another aspect that has been improved in saliency is memory, and more specifically, spatial memory; VR environments allow one to learn activities where memorization and recall are required. The spatial features of VR scenes are significantly favorable in boosting the spatial memory since children move across environment and encode spatial knowledge, thus honing cognitive mapping abilities.

Adaptive Mechanisms and Their Impact

Recent empirical study of adaptive mechanisms in VR video game settings has found the following essential factors in maximizing the results of cognitive rehabilitation: real-time difficulty modulation, interactive feedback, and goal setting that is dynamically set (Gomez et al., 2021). With the help of such adaptive features, the risks of under- or over-challenging participants are reduced as motivation is preserved and helps them to acquire skills in small increments. Evidence-based research also suggests that individuals who are involved in adaptive VR therapy note increased perceptions of accomplishment and increased self-efficacy in cognitive aspects.

Challenges and Limitations

Adaptive VR based interventions have a few economic and practical limitations despite their therapeutic potential. One of the main shortcomings is related to accessibility because the cost of VR hardware and software development, as well as the cost of maintenance, makes a universal application of VR in educational and clinical settings unrealistic. Based on this, there is limited access for children with low socioeconomic backgrounds to these interventions.

Future Potential and Recommendations

The evidence shows the significant potential of adaptive VR therapies to transform cognitive rehabilitation among school-aged populations. There should be an urgency to maximize their potential by increasing accessibility by means of cost-effective interventions and to incorporate VR therapy modalities into regular educational and rehabilitation curricula. These efforts together with creation of standardized assessment tools would facilitate consistency in the measurement of cognitive improvements under different research designs and models of interventions.

Discussion

This review clarifies the possibility of the adaptive purpose of virtual reality (VR) games to promote cognitive rehabilitation among school-aged children with a particular aim of improving attention, memory, and executive functions, and problem-solving abilities. In contrast to the traditional rehabilitation modalities, the VR therapy entails enhanced interactivity and immersion, thus alleviating motivational deficits that Christ and traditionally practiced modalities often face. The ability of VR systems to dynamically simulate task difficulty is critical to ensure the children get one-on-one training based on their performance resulting in gradual development of skills without causing overload (Huang et al., 2021).

The above flexibility is especially useful with children with learning disabilities or attentional disorders as it allows having the interventions designed to specifically cope with their unique cognitive difficulties. In addition, the inclusion of interactive feedback functionalities and the element of gamifications in VR environments enhances the learning process by providing feedback in real-time regarding performance and promoting long-term interest.

However, VR technology is rather expensive and has minimal access and its methodology is also heterogeneous, which puts a significant impediment to the general adoption of the technology. Moreover, the possible negative outcomes like motion sickness and greater exposure to the screen need additional empirical investigations. Though the existing research indicates the short-term advantages, longitudinal studies are also necessary to determine the sustainability of the VR-induced cognitive improvements (Bassano et al., 2021). To establish methodological consistency in the psychometric assessment of cognitive gains achieved with the help of various models of interventions, the need to standardize assessment tools comes up. VR technology could be developed further to overcome existing limitations and, therefore, became a more useful and effective instrument of cognitive rehabilitation, even in stroke patients.

Conclusion

Adaptive virtual reality (VR) games have been found to be a major progression in cognitive rehabilitative programs, a means of providing an interactive and engaging modality to develop cognitive skills in school-aged children. The ability to customize therapeutic sessions by using real-time adjustment and feedback systems is necessary to make sure that the interventions are according to the learning preferences of the children. Empirical evidence proves that VR-based cognitive therapy provides significant motivation, memory, executive functioning, and problem-solving improvements, which makes it an important tool in children with cognitive limitations. However, the issues of accessibility, cost, and standardization should be resolved to enable more extensive implementation. The second important area that ought to be explored by future studies is the long-term outcome of VR-based interventions and the development of cost-efficient methods that would be applicable on a large-scale level. Cognitive rehabilitation programs can be made more accessible through the abilities of VR technology and, thus, improve the educational and developmental performance of children with cognitive impairment.

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