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Efficacy of Virtual Reality Games in Enhancing Motor Coordination in Children with Dyspraxia: A Randomized Controlled Trial

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ABSTRACT

Background: Children with dyspraxia often face challenges in motor coordination, significantly affecting their functional independence and quality of life. Virtual reality (VR)-based interventions have shown promise in improving motor skills through engaging, interactive environments.

Objective: This study aimed to evaluate the effectiveness of VR-based interventions in improving motor coordination, balance, fine motor skills, and quality of life in children with dyspraxia compared to conventional therapy.

Methods: A randomized controlled trial was conducted with 60 children aged 6–12 years diagnosed with dyspraxia, randomized into intervention (VR-based therapy) and control (standard physiotherapy) groups (n=30 per group). The intervention group participated in VR sessions three times a week for 12 weeks, focusing on motor tasks such as object manipulation and balance. Motor coordination was assessed using the Movement Assessment Battery for Children (MABC), with secondary outcomes including balance, fine motor skills, and quality of life. Data were analyzed using SPSS version 25 with repeated-measures ANOVA.

Results: The intervention group showed a significant improvement in MABC scores (mean change: 7.3 ± 3.1) compared to the control group (mean change: 1.8 ± 3.4; p<0.001p<0.001). Balance improved by 12.9% (p<0.001p<0.001), fine motor skills by 9.7% (p<0.001p<0.001), and quality of life by 11.8% (p<0.001p<0.001).

Conclusion: VR-based interventions significantly enhanced motor coordination and related outcomes in children with dyspraxia, demonstrating their potential as an effective rehabilitation tool.

INTRODUCTION

Virtual reality (VR) technology has emerged as a promising tool in the rehabilitation of motor skills in pediatric populations, particularly for children with developmental coordination disorders (DCD) and dyspraxia. These conditions, characterized by difficulties in planning and executing motor tasks, significantly impact academic, social, and physical activities, posing challenges to children's overall quality of life. Traditional therapeutic approaches often face limitations, such as low engagement and adherence among young patients, necessitating innovative interventions that can sustain motivation and participation. VR has gained attention for its immersive and interactive environment, which facilitates motor skill training in a controlled, engaging, and customizable setting. This technology leverages sensory feedback and repetitive task-based learning to enhance fine and gross motor skills, predictive motor control, and action planning (1, 2).

Several studies have explored the efficacy of VR interventions in improving motor coordination and related functions in children with motor impairments, including those with dyspraxia. Non-immersive VR systems, such as the Nintendo Wii, have been widely utilized due to their accessibility and ability to engage children in physical activity through gaming. More advanced immersive VR systems, coupled with wearable haptic devices, have demonstrated additional potential in targeting upper limb function and enhancing sensory-motor integration (3, 4). Despite these promising findings, the evidence base remains inconsistent due to methodological variability, small sample sizes, and a lack of standardized protocols. Moreover, while VR has shown potential to improve specific aspects such as motor imagery, dynamic balance, and visual-motor coordination, its impact on other domains, such as gross motor function, is less conclusive (5, 6).

Importantly, VR interventions have proven to be more than just a therapeutic tool; they also address psychological and emotional aspects by providing a motivating and enjoyable medium for rehabilitation. Studies report high levels of adherence and positive responses among children, which are critical for the success of long-term therapeutic regimens. However, the variability in the design and implementation of VR interventions necessitates further research to identify optimal protocols and determine the most effective applications for specific motor impairments, including those seen in dyspraxia (7, 8).

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In light of the increasing interest in VR-based motor rehabilitation, this study aims to synthesize existing evidence on the use of VR interventions to enhance motor coordination in children with dyspraxia. By critically evaluating the outcomes and limitations of current research, the goal is to inform future clinical practices and contribute to the development of evidence-based guidelines for VR integration in pediatric rehabilitation programs. The growing body of research underscores the need for high-quality studies to establish the long-term efficacy and feasibility of VR interventions, particularly as an adjunct to conventional therapy (9, 10). This exploration into VR's potential not only highlights its therapeutic benefits but also paves the way for its broader application in clinical settings, ultimately aiming to improve the functional outcomes and quality of life for children with dyspraxia.

MATERIAL AND METHODS

This study employed a randomized controlled trial (RCT) design to investigate the efficacy of virtual reality (VR) conducted at Teaching Hospital Shadara, Lahore, Pakistan. A total of 60 participants were enrolled, with 30 children allocated to the intervention group and 30 to the control group. Participants were recruited from pediatric rehabilitation clinics following a thorough screening process to ensure eligibility based on predefined inclusion and exclusion criteria. Inclusion criteria required children to have a clinical diagnosis of dyspraxia confirmed by a pediatric neurologist or developmental specialist, to be aged between 6 and 12 years, and to have no severe cognitive, visual, or musculoskeletal impairments that could interfere with their participation in the intervention. Parents or guardians provided written informed consent before enrollment in compliance with ethical guidelines.

The study protocol adhered to the principles outlined in the Declaration of Helsinki, ensuring ethical standards in all research activities. Ethical approval was obtained from the institutional review board of the host institution prior to commencement. Randomization was conducted using computer-generated random numbers, and participants were stratified by age and sex to ensure group comparability. Allocation concealment was achieved using sealed opaque envelopes. Blinding of outcome assessors was implemented to minimize potential bias during data collection and analysis. The intervention group participated in a structured VR-based motor training program designed to improve motor coordination, fine motor skills, and action planning. Sessions were conducted using immersive VR systems over a period of 12 weeks, with participants attending three 45-minute sessions per week. The VR environment was designed to include gamified tasks targeting motor functions, such as object manipulation, coordination games, and balance exercises. The control group received standard physiotherapy based on conventional approaches for motor skill development, following current clinical guidelines.

Data collection involved baseline and post-intervention assessments using validated tools, such as the Movement Assessment Battery for Children (MABC), to evaluate motor coordination. Additional outcome measures included parent-reported questionnaires and clinician-administered tests to assess functional abilities and quality of life. Data were collected by trained professionals who were blinded to group allocation to ensure unbiased measurements. All assessments were conducted in a clinical setting under standardized conditions.

Data analysis was performed using SPSS software version 25. Descriptive statistics, including means and standard deviations, were used to summarize participant characteristics and baseline data. Between-group comparisons were conducted using independent t-tests for continuous variables and chi-square tests for categorical variables. Changes in outcome measures from baseline to post-intervention were analyzed using repeated-measures ANOVA, with group as the between-subject factor and time as the within-subject factor. Statistical significance was set at a p-value of less than 0.05. Throughout the study, rigorous procedures were followed to ensure data integrity and compliance with ethical standards. The findings are intended to contribute to the evidence base for using VR interventions in pediatric motor rehabilitation, specifically targeting children with dyspraxia.

RESULTS

The analysis revealed significant improvements in motor coordination and related outcomes for the intervention group compared to the control group. A total of 60 participants completed the study, with no significant differences in baseline characteristics between groups, ensuring comparability. The descriptive statistics and baseline comparisons are summarized in Table 1 below.

Table 1. Baseline Characteristics of Participants

Characteristic	Intervention Group (n=30)	Control Group (n=30)	p-value
Age (years, mean ± SD)	8.5 ± 1.2	8.6 ± 1.1	0.762
Male, n (%)	16 (53.3%)	17 (56.7%)	0.785
MABC Score (mean ± SD)	12.1 ± 3.5	12.3 ± 3.7	0.843

The groups were well-matched in terms of demographic and clinical characteristics (p>0.05p>0.05), indicating that any observed differences in outcomes could be attributed to the intervention. The primary outcome, motor coordination, was measured using the Movement Assessment Battery for Children (MABC). The intervention group demonstrated a substantial improvement in post-intervention scores compared to the control group, as shown in Table 2.

The intervention group showed a mean improvement of 7.3 points (95% CI: 6.5 to 8.1), while the control group exhibited a modest gain of 1.8 points (95% CI: 1.2 to 2.4). This resulted in a significant between-group difference of 5.5 points

(p<0.001p<0.001). Secondary measures assessed balance, fine motor skills, and quality of life. Participants in the intervention group exhibited significantly greater improvements across all secondary outcomes compared to the control group, as summarized in Table 3

Table 2. Motor Coordination Scores (MABC)

Group	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	Mean Change (95% CI)	p-value
Intervention Group	12.1 ± 3.5	19.4 ± 3.1	7.3 (6.5 to 8.1)	<0.001
Control Group	12.3 ± 3.7	14.1 ± 3.4	1.8 (1.2 to 2.4)	<0.001
Between-Group Difference	-	-	5.5 (4.6 to 6.4)	<0.001

Table 3. Secondary Outcome Measures

Measure	Intervention Group (Mean ± SD)	Control Group (Mean ± SD)	Between-Group Difference (95% CI)	p-value
Balance Score (Post)	85.3 ± 5.1	72.4 ± 6.7	12.9 (10.8 to 15.0)	<0.001
Fine Motor Skills (%)	88.2 ± 4.5	78.5 ± 5.2	9.7 (7.8 to 11.6)	<0.001
Quality of Life (Post)	85.7 ± 6.2	73.9 ± 5.8	11.8 (9.4 to 14.2)	<0.001

The intervention group achieved an 85.3% balance score compared to 72.4% in the control group, representing a significant improvement of 12.9% (p<0.001p<0.001). Similarly, fine motor skill performance increased by 9.7% and quality of life scores by 11.8%, both of which were statistically significant (p<0.001p<0.001). Advanced statistical analysis using repeated-measures ANOVA confirmed a significant interaction effect between time and group for motor coordination scores (F(1,58)=52.34,p<0.001,η2=0.47F(1,58)=52.34,p<0.001,η2 =0.47). Post hoc tests demonstrated that improvements in the intervention group were significantly greater over time compared to the control group. Correlation analyses further revealed a strong relationship between VR intervention and enhancements in balance and fine motor skills (R2=0.65,p<0.001R2=0.65,p<0.001).

Adherence to the intervention was high, with 95% of participants in the intervention group completing all sessions. No adverse events were reported, underscoring the safety and feasibility of the VR-based program for children with dyspraxia. These results provide robust evidence that VR interventions significantly enhance motor coordination, balance, fine motor skills, and quality of life in children with dyspraxia compared to conventional therapy, highlighting their potential as an effective rehabilitation tool.

DISCUSSION

The findings of this randomized controlled trial demonstrated the significant potential of virtual reality (VR)-based interventions in improving motor coordination, balance, fine motor skills, and quality of life in children with dyspraxia. These results align with and expand upon previous research indicating that VR interventions can provide a motivating and effective approach to pediatric motor rehabilitation. Notably, the improvements observed in motor coordination, as measured by the Movement Assessment Battery for Children (MABC), were consistent with earlier studies that highlighted the benefits of VR in enhancing fine motor control and predictive motor skills in children with developmental coordination disorders (EbrahimiSani et al., 2020; Abdelhaleem et al., 2022).

The intervention group demonstrated significantly greater improvements in motor coordination compared to the control group, a finding that reinforces the efficacy of immersive VR environments in promoting neuroplasticity through repetitive, goal-oriented tasks. This result mirrors prior evidence that VR provides enhanced sensory feedback and engagement, leading to better adherence and outcomes in pediatric populations (Tieri et al., 2018). Additionally, the improvements in balance and fine motor skills were in line with studies that reported the efficacy of VR in targeting dynamic postural control and motor precision (Dana et al., 2019; Zhang et al., 2020). However, the magnitude of improvement in this study surpassed that of some prior research, possibly due to the structured protocol, immersive system design, and frequent intervention sessions.

The study also revealed high adherence rates, with 95% session completion in the VR group, reflecting the motivating nature of the VR intervention. This contrasts with traditional physiotherapy, where adherence is often hindered by monotony and lack of engagement. These findings underscored the importance of integrating innovative, gamified technologies into rehabilitation programs to sustain motivation, particularly in younger populations (8-14).

Despite the strengths of this study, several limitations must be acknowledged. First, the sample size, although adequate for detecting significant differences, was relatively small and limited to a specific age group, which may affect the generalizability of the findings. Larger multicenter trials would be necessary to validate these results across diverse populations. Additionally, while the study employed a robust randomized controlled design, the lack of long-term follow-up limited the ability to assess the durability of the observed improvements. Previous research has suggested that long-term adherence to VR interventions is crucial for maintaining motor function gains (15), indicating the need

for future studies to explore sustained outcomes over extended periods (16-19).

Another limitation was the use of a single VR platform, which may not capture the full potential of various VR systems. Differences in hardware, software, and task designs across VR platforms could yield varying results, emphasizing the need for comparative studies to determine the most effective technologies for specific motor impairments. Additionally, while outcome assessors were blinded, complete blinding of participants was not feasible, potentially introducing performance bias (20-23).

This study had several strengths, including its rigorous methodology, adherence to ethical guidelines, and the use of validated assessment tools. The inclusion of multiple outcome measures allowed for a comprehensive evaluation of the intervention's impact. The structured protocol ensured consistency and reliability, while the application of advanced statistical analyses strengthened the validity of the findings. Future research should focus on addressing the limitations identified in this study. Large-scale trials with diverse participant populations and extended follow-up periods are recommended to confirm the generalizability and sustainability of VR-based interventions. Additionally, exploring the integration of VR with conventional therapies could provide insights into synergistic effects. Investigating cost-effectiveness and accessibility will also be critical for implementing VR interventions on a broader scale, particularly in low-resource settings (24).

CONCLUSION

In conclusion, this study provided compelling evidence for the efficacy of VR in improving motor coordination, balance, fine motor skills, and quality of life in children with dyspraxia. The findings highlighted the potential of VR as an innovative, engaging, and effective tool in pediatric rehabilitation. While limitations existed, the strengths of the study underscored its contribution to the growing body of evidence supporting VR's role in enhancing motor function in children with developmental motor disorders. Further research is warranted to optimize its application and maximize its impact on clinical outcomes.

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