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EFFECTIVENESS OF VIRTUAL AND AUGMENTED REALITY-BASED INTERVENTIONS COMPARED WITH CONVENTIONAL PHYSIOTHERAPY FOR IMPROVING SENSORIMOTOR SKILLS IN CHILDREN WITH AUTISM SPECTRUM DISORDER: A PILOT RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

Background: Autism Spectrum Disorder (ASD) is linked to deficiencies in motor coordination, sensory processing, and sensorimotor integration, all of which can have a detrimental impact on independence in day-to-day activities Virtual reality (VR) and augmented reality (AR) are emerging tools to enhance rehabilitation outcomes in paediatric populations.
Objective: To evaluate the efficacy of traditional physiotherapy with VR and AR-based training in enhancing sensorimotor and functional results in kids with ASD.
Methods: Methods Twenty-four kids with ASD, ages 6 to 12, took part in the study and were split into two groups of twelve at random. Group B received traditional physiotherapy for 12 weeks; whereas Group A received training based on virtual reality and augmented reality. The 6-Minute Walk Test (6MWT), Vineland Adaptive Behavior Scales (VABS), Child Sensory Profile-2, Autism Motor Assessment Scale (AMAS) and salivary biomarkers (α-amylase, cortisol, and serotonin) were among the outcome measurements. Evaluations were conducted both prior to and during the intervention period.
Results: After the intervention, both groups showed statistically significant improvements. On the other hand, Group A showed more improvement. Group A saw improvements in daily living skills from 56.0±6.40 to 69.1±6.86, VABS communication from 58.1±6.54 to 68.6±4.76, AMAS score from 35.1±3.45 to 45.3±2.87, and 6MWT distance from 315.8±4.28 to 369.8±3.83. Salivary biomarker analysis revealed that serotonin rose from 59.1±3.40 to 94.3±3.73, while α-amylase (229.9±8.37 to 155.7±7.55) and cortisol (0.8±0.04 to 0.5±0.03) decreased. Group B also made progress, although it was less significant. Comparisons made after the intervention showed that Group A had considerably better results for every variable.
Conclusion: In children with ASD, VR and AR-based training was more successful than traditional physiotherapy in enhancing sensorimotor skills, adaptive functioning, exercise tolerance, and stress-related biomarkers. These results lend credence to the application of immersive technologies in pediatric neurorehabilitation.

KEYWORDS: Autism Spectrum Disorder, Virtual Reality, Augmented Reality, Physiotherapy, Sensorimotor Skills, Salivary Biomarkers, VABS, AMAS, 6-Minute Walk Test

INTRODUCTION

The complex neurodevelopmental illness known as autism spectrum disorder is marked by difficulties with social interaction, communication, repetitive behaviors, limited interests, and restricted activity patterns.(1) It is one of the most often identified developmental diseases in childhood, affecting about 1 in 68 children and frequently having a long-term impact on general quality of life.[2]
Although there is no single cure for Autism Spectrum Disorder, research has shown that individualized educational and behavioral interventions can lead to meaningful improvements for both children and their families. Approaches such as TEACCH, Applied Behavior Analysis, the Early Intensive Behavioral Intervention, and the Denver Model have been found to improve communication, behavior, and daily living abilities. As the number of children diagnosed with ASD continues to increase, researchers have focused more on technology-assisted methods to strengthen and complement these interventions.(4)
Several forms of technology have been introduced as therapeutic tools for children with ASD, including robotics, interactive video modeling, mobile applications, touchscreen devices, wearable technologies such as Google

Glass, and Virtual Reality. These technologies offer engaging and interactive ways to support learning, communication, and skill development.(5)

Children with ASD often show strong interest in digital learning environments and may respond positively to computer-based interventions. In addition, technology-assisted home training may help reduce the time and effort required from therapists while still supporting continuous practice and skill development. (8)

Among emerging digital rehabilitation tools, Virtual Reality has gained considerable attention as a promising approach for addressing the psychological and functional needs of individuals with Autism Spectrum Disorder.(9) Over the past two decades, VR has been progressively introduced into neurocognitive rehabilitation, demonstrating potential benefits in improving behavioral and cognitive outcomes.(10) A growing body of research over the last decade has further supported its effectiveness across different system designs and levels of symptom severity.(11)

Recent advances have also enhanced VR applications by incorporating psychological principles into intervention design and by refining system features that improve user interaction and engagement. (12) VR environments are particularly advantageous because they reduce real-world social pressure while providing controlled, realistic, and safe training settings. This structured and controlled setting enables children with Autism Spectrum Disorder to practice important skills in a safe and supportive environment. As a result, therapy sessions may become more efficient and may reduce the amount of time needed for conventional treatment approaches. (13-16)

At present, Virtual Reality-based interventions are being used in several areas of training. These include improving social interaction, communication abilities, emotional understanding and self-regulation, as well as daily living tasks such as shopping, driving, and safely crossing roads. VR has also been applied in cognitive training programs, showing its wide range of uses as a rehabilitation method. [(17 – 19)]

MATERIALS AND METHODS

This study was carried out as a randomized comparative interventional trial to evaluate the effectiveness of Virtual Reality and augmented reality-based training compared with conventional physiotherapy in improving sensorimotor and functional abilities in children with Autism Spectrum Disorder. The research was conducted in special schools in Chennai and in rehabilitation centers, including the Outpatient Physiotherapy Department of ACS Medical College and Hospital, NIPMED, and Dr. M.G.R. Educational & Research Institute. These settings offered both educational and clinical environments that were appropriate for pediatric neurorehabilitation.

Twenty-four children with ASD, aged six to twelve, were chosen based on predetermined inclusion and exclusion criteria. The study included children who were medically fit to engage in physiotherapy sessions, had a confirmed diagnosis of ASD, and could comprehend basic verbal commands. Children were not allowed to participate if they had significant musculoskeletal abnormalities, uncontrolled neurological illnesses, or any other medical condition that would interfere.

The participants were split into two groups of twelve kids each at random. Group B received traditional physiotherapy, while Group A received rehabilitation based on VR and AR. All participants' parents or legal guardians provided written informed permission prior to the intervention's commencement. The institutional ethics committee's authorized ethical requirements were adhered to throughout the entire investigation.

Prior to the start of the intervention, each participant had a baseline assessment. In order to evaluate both gross and fine motor skills in children with Autism Spectrum Disorder, Autism Motor Assessment Scale (AMAS) serves as a structured observational instrument. Stress levels and neurochemical alterations standardized outcome measures were employed, including salivary biomarkers such alpha-amylase, cortisol, and serotonin. The Vineland Adaptive Behavior Scales, the Child Sensory Profile-2 were used to measure emotional and functional performance. The 6-Minute Walk Test was used to measure exercise capacity and functional endurance. The same evaluation instruments were utilized once more to gauge improvements following the 12-week intervention period.

Children in Group A took part in a structured VR and AR-based rehabilitation program designed to enhance sensory integration, fine motor coordination, and gross motor skills. Immersion virtual activities like obstacle navigation, balance exercises, and interactive movement games that required coordination, postural control, and spatial awareness were included of the 20–30 minute gross motor training sessions. Fine motor training sessions lasted 15–20 minutes and focused on precision-based tasks such as virtual object manipulation, puzzle solving, drawing and tracing activities, and sequential button-press tasks, with each activity lasting approximately 4–5 minutes and progressively increasing in difficulty. Sensory integration training sessions also lasted 15–20 minutes and included proprioceptive, visual, auditory, and vestibular stimulation activities delivered through immersive virtual environments, with graded exposure to enhance sensory processing and integration.(3)

Group B participants received conventional physiotherapy interventions matched in duration and therapeutic intent. Gross motor training sessions of 20–30 minutes included real-world obstacle courses, balance board exercises, ball games, and strengthening activities using resistance bands and weighted objects. Fine motor training sessions of 15–20 minutes included manipulation of physical objects such as beads and pegs, puzzle-solving tasks, handwriting and tracing exercises, and functional activities such as buttoning and zipping. Sensory integration therapy sessions of 15–20 minutes included proprioceptive exercises using weighted vests and

resistance equipment, visual and auditory processing tasks, and vestibular stimulation using swings, therapy balls, and balance boards. (6, 7)
Both groups received supervised interventions over a total duration of 12 weeks. The frequency and progression of exercises were standardized to ensure comparability between groups while allowing gradual increase in task complexity based on participant tolerance and performance. Statistical analysis was performed on pre- and post-intervention data to evaluate within-group and between-group differences in outcome measures, and significance was determined to assess the comparative effectiveness of VR and AR-based training versus conventional physiotherapy.

DATA ANALYSIS
The collected data were analyzed using descriptive and inferential statistics with Statistical Package for the Social Sciences (SPSS) version 24. Normality of the data was assessed using the Shapiro–Wilk test, and a significance level of $p < 0.05$ with a 95% confidence interval was applied. Since the variables were continuous and normally distributed, parametric tests were used for analysis. Paired t-tests were used for within-group comparisons, while Independent t-tests were used for between-group comparisons, with $p < 0.001$ considered highly statistically significant.

Table-1: Comparison of pre-test & post-test values for Group A - AMAS

Group A		N	Mean	Std. Deviation	Std. Error Mean	t- value	P value
Balance & Coordination	**Pre**	12	5.1	0.79	0.229	-23.216	< 0.001
	Post	12	8.6	0.79	0.229		
Target-Oriented Motor Skills	**Pre**	12	5.7	0.65	0.188	-24.106	< 0.001
	Post	12	9.3	0.62	0.179		
Strength & Mobility	**Pre**	12	5.2	0.94	0.271	-24.893	< 0.001
	Post	12	8.4	0.90	0.260		
Fine Motor Precision	**Pre**	12	5.8	0.75	0.218	-23.452	< 0.001
	Post	12	9.1	0.79	0.229		
Functional Fine Motor Tasks	**Pre**	12	7.5	0.90	0.261	-22.978	< 0.001
	Post	12	11.5	0.90	0.261		
Total AMAS	**Pre**	12	35.1	3.45	0.996	-17.703	< 0.001
	Post	12	45.3	2.87	0.829		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group A table shows that there is significant difference between pre-test and post-test.

Table-2: Comparison of pre-test & post-test values for Group A - VABS

Group A		N	Mean	Std. Deviation	Std. Error Mean	t- value	P value
Communication	**Pre**	12	58.1	6.54	1.889	-16.267	< 0.001
	Post	12	68.6	4.76	1.373		
Daily Living	**Pre**	12	56.0	6.40	1.846	-50.339	< 0.001
	Post	12	69.1	6.86	1.979		
Social Skill and Relationship	**Pre**	12	54.6	7.05	2.036	-33.240	< 0.001
	Post	12	67.2	6.35	1.833		
Physical Activity	**Pre**	12	32.3	3.34	0.964	-34.898	< 0.001
	Post	12	43.3	2.80	0.808		
	Pre	12	51.3	4.14	1.196	-26.389	< 0.001

Problem Behavior	**Post**	12	63.3	3.28	0.946		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group A table shows that there is significant difference between pre-test and post-test.

Table-3: Comparison of pre-test & post-test values for Group A - Salivary Biomarkers

Group A		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t- value**	**P value**
α-Amylase	**Pre**	12	229.9	8.37	2.417	125.438	< 0.001
	Post	12	155.7	7.55	2.179		
Cortisol	**Pre**	12	0.8	0.04	0.011	110.022	< 0.001
	Post	12	0.5	0.03	0.008		
Serotonin	**Pre**	12	59.1	3.40	0.981	-115.712	< 0.001
	Post	12	94.3	3.73	1.075		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group A table shows that there is significant difference between pre-test and post-test.

Table-4: Comparison of pre-test & post-test values for Group A – 6MWT

Group A		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t- value**	**P value**
6MWT	**Pre**	12	315.8	4.28	1.236	-98.096	< 0.001
	Post	12	369.8	3.83	1.107		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group A table shows that there is significant difference between pre-test and post-test.

Table-5: Comparison of pre-test & post-test values for Group A - Child Sensory Profile

Group A		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t- value**	**P value**
Auditory	Pre	12	32.8	1.42	0.411	11.231	< 0.001
	Post	12	22.8	3.76	1.086		
Visual	Pre	12	29.6	1.68	0.484	9.839	< 0.001
	Post	12	21.8	3.52	1.016		
Touch	Pre	12	46.4	2.35	0.679	12.277	< 0.001
	Post	12	33.4	4.23	1.221		
Movement	Pre	12	32.9	2.71	0.783	32.833	< 0.001
	Post	12	23.6	2.71	0.783		
Body Position	Pre	12	31.3	3.77	1.089	26.196	< 0.001
	Post	12	21.4	3.96	1.145		
Oral	Pre	12	41.0	2.89	0.835	12.646	< 0.001
	Post	12	30.5	4.70	1.357		
Conduct	Pre	12	36.5	2.32	0.669	11.122	< 0.001

	Post	12	27.3	3.03	0.873		
Social Emotional	Pre	12	57.1	2.19	0.633	17.364	< 0.001
	Post	12	41.2	4.17	1.205		
Attentional	Pre	12	45.9	2.50	0.723	20.026	< 0.001
	Post	12	33.0	4.35	1.255		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group A table shows that there is significant difference between pre-test and post-test.

Table-6: Comparison of pre-test & post-test values for Group B - AMAS

Group B		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t- value**	**P value**
Balance & Coordination	**Pre**	12	5.0	0.60	0.174	-2.691	0.021
	Post	12	5.8	0.75	0.218		
Target-Oriented Motor Skills	**Pre**	12	6.8	0.75	0.218	-13.000	< 0.001
	Post	12	7.8	0.83	0.241		
Strength & Mobility	**Pre**	12	5.1	0.79	0.229	-25.000	< 0.001
	Post	12	7.2	0.83	0.241		
Fine Motor Precision	**Pre**	12	5.8	0.75	0.218	-16.316	< 0.001
	Post	12	7.6	0.90	0.260		
Functional Fine Motor Tasks	**Pre**	12	7.7	0.65	0.188	-10.795	< 0.001
	Post	12	9.8	0.75	0.218		
Total AMAS	**Pre**	12	34.6	3.34	0.965	-30.834	< 0.001
	Post	12	39.2	3.46	0.999		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group B table shows that there is significant difference between pre-test and post-test.

Table-7: Comparison of pre-test & post-test values for Group B - VABS

Group A		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t- value**	**P value**
Communication	**Pre**	12	59.3	6.43	1.855	-3.386	0.006
	Post	12	62.8	5.41	1.562		
Daily Living	**Pre**	12	57.0	6.40	1.846	-14.681	< 0.001
	Post	12	62.8	5.94	1.715		
Social Skill and Relationship	**Pre**	12	55.6	7.05	2.036	-9.641	< 0.001
	Post	12	59.9	6.56	1.893		
Physical Activity	**Pre**	12	33.2	3.49	1.006	-10.258	< 0.001
	Post	12	37.3	2.30	0.664		
Problem Behavior	**Pre**	12	51.4	4.06	1.171	-8.396	< 0.001
	Post	12	56.2	3.21	0.928		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group B table shows that there is significant difference between pre-test and post-test.

Table-8: Comparison of pre-test & post-test values for Group B - Salivary Biomarkers

Group B		N	Mean	Std. Deviation	Std. Error Mean	t- value	P value
α-Amylase	**Pre**	12	227.1	7.75	2.238	67.786	< 0.001
	Post	12	197.6	7.40	2.137		
Cortisol	**Pre**	12	0.8	0.04	0.011	49.749	< 0.001
	Post	12	0.7	0.03	0.009		
Serotonin	**Pre**	12	61.3	3.11	0.897	-59.908	< 0.001
	Post	12	79.5	3.75	1.084		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group B table shows that there is significant difference between pre-test and post-test.

Table-9: Comparison of pre-test & post-test values for Group B – 6MWT

Group B		N	Mean	Std. Deviation	Std. Error Mean	t- value	P value
6MWT	**Pre**	12	318.8	1.76	0.509	-85.6	< 0.001
	Post	12	343.1	1.78	0.514		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group B table shows that there is significant difference between pre-test and post-test.

Table-10: Comparison of pre-test & post-test values for Group B - Child Sensory Profile

Group B		N	Mean	Std. Deviation	Std. Error Mean	t- value	P value
Auditory	Pre	12	32.6	2.02	0.583	9.798	< 0.001
	Post	12	28.6	1.88	0.543		
Visual	Pre	12	29.2	1.75	0.505	8.248	< 0.001
	Post	12	25.6	2.11	0.609		
Touch	Pre	12	46.5	2.28	0.657	13.985	< 0.001
	Post	12	40.3	1.72	0.497		
Movement	Pre	12	32.7	1.72	0.497	12.113	< 0.001
	Post	12	28.4	1.44	0.417		
Body Position	Pre	12	33.0	2.59	0.749	20.055	< 0.001
	Post	12	28.2	2.37	0.683		
Oral	Pre	12	42.3	1.97	0.569	10.383	< 0.001
	Post	12	36.5	2.88	0.830		
Conduct	Pre	12	35.5	2.47	0.712	11.651	< 0.001
	Post	12	31.6	2.31	0.668		
Social Emotional	Pre	12	57.8	2.66	0.767	7.931	< 0.001
	Post	12	48.8	4.04	1.167		
Attentional	Pre	12	46.7	2.57	0.742	11.285	< 0.001
	Post	12	38.9	3.40	0.981		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t-test and p-value between pre-test and post-test. This Group B table shows that there is significant difference between pre-test and post-test.

Table -11: Comparison of post-test values of Group A & Group B - AMAS

PARAMETER			N	Mean	Std. Deviation	Std. Error Mean	**t test**	**P value**
AMAS	**Balance & Coordination**	Group A	12	8.6	0.79	0.229	8.971	< 0.001
		Group B	12	5.8	0.75	0.218		
	Target-Oriented Motor Skills	Group A	12	9.3	0.62	0.179	4.715	< 0.001
		Group B	12	7.8	0.83	0.241		
	Strength & Mobility	Group A	12	8.4	0.90	0.260	3.527	0.002
		Group B	12	7.2	0.83	0.241		
	Fine Motor Precision	Group A	12	9.1	0.79	0.229	4.331	< 0.001
		Group B	12	7.6	0.90	0.260		
	Functional Fine Motor Tasks	Group A	12	11.5	0.90	0.261	5.149	< 0.001
		Group B	12	9.8	0.75	0.218		
	Total AMAS	Group A	12	45.3	2.87	0.829	4.752	< 0.001
		Group B	12	39.2	3.46	0.999		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t test, and p-value between post-test within Group – A & Group – B. There is a statistically significant difference between the post-test values of Group A and Group B.

Table -12: Comparison of post-test values of Group A & Group B - VABS

PARAMETER			N	Mean	Std. Deviation	Std. Error Mean	**t test**	**P value**
VABS	**Communication**	Group A	12	68.6	4.76	1.373	2.804	0.010
		Group B	12	62.8	5.41	1.562		
	Daily Living	Group A	12	69.1	6.86	1.979	2.419	0.024
		Group B	12	62.8	5.94	1.715		
	Social Skill and Relationship	Group A	12	67.2	6.35	1.833	2.751	0.012
		Group B	12	59.9	6.56	1.893		
	Physical Activity	Group A	12	43.3	2.80	0.808	5.735	< 0.001
		Group B	12	37.3	2.30	0.664		
	Problem Behaviour	Group A	12	63.3	3.28	0.946	5.344	< 0.001
		Group B	12	56.2	3.21	0.928		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t test, and p-value between post-test within Group – A & Group – B. There is a statistically significant difference between the post-test values of Group A and Group B.

Table -13: Comparison of post-test values of Group A & Group B - Salivary Biomarkers

PARAMETER			**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t test**	**P value**
Salivary Biomarkers	**α-Amylase**	**Group A**	12	155.7	7.55	2.179	-13.734	< 0.001
		Group B	12	197.6	7.40	2.137		
	Cortisol	**Group A**	12	0.5	0.03	0.008	-14.423	< 0.001
		Group B	12	0.7	0.03	0.009		
	Serotonin	**Group A**	12	94.3	3.73	1.075	9.716	< 0.001
		Group B	12	79.5	3.75	1.084		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t test, and p-value between post-test within Group – A & Group – B. There is a statistically significant difference between the post-test values of Group A and Group B.

Table -14: Comparison of post-test values of Group A & Group B – 6MWT

PARAMETER		N	Mean	Std. Deviation	Std. Error Mean	**t test**	**P value**
6MWT	**Group A**	12	369.8	3.83	1.107	21.920	< 0.001
	Group B	12	343.1	1.78	0.514		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t test, and p-value between post-test within Group – A & Group – B. There is a statistically significant difference between the post-test values of Group A and Group B.

Table -15: Comparison of post-test values of Group A & Group B - Child Sensory Profile

PARAMETER			N	Mean	Std. Deviation	Std. Error Mean	**t test**	**P value**
Child Sensory Profile	Auditory	Group A	12	22.8	3.76	1.086	-4.736	< 0.001
		Group B	12	28.6	1.88	0.543		
	Visual	Group A	12	21.8	3.52	1.016	-3.237	0.004
		Group B	12	25.6	2.11	0.609		
	Touch	Group A	12	33.4	4.23	1.221	-5.245	< 0.001
		Group B	12	40.3	1.72	0.497		
	Movement	Group A	12	23.6	2.71	0.783	-5.450	< 0.001
		Group B	12	28.4	1.44	0.417		
	Body Position	Group A	12	21.4	3.96	1.145	-5.063	< 0.001
		Group B	12	28.2	2.37	0.683		
	Oral	Group A	12	30.5	4.70	1.357	-3.772	0.001
		Group B	12	36.5	2.88	0.830		

	Conduct	Group A	12	27.3	3.03	0.873	-3.865	0.001
		Group B	12	31.6	2.31	0.668		
	Social Emotional	Group A	12	41.2	4.17	1.205	-4.571	< 0.001
		Group B	12	48.8	4.04	1.167		
	Attentional	Group A	12	33.0	4.35	1.255	-3.714	0.001
		Group B	12	38.9	3.40	0.981		

(*P value < 0.05 - Statistically Significant)

The above table reveals the Mean, SD, t test, and p-value between post-test within Group – A & Group – B. There is a statistically significant difference between the post-test values of Group A and Group B.

RESULT

In both Group A and Group B, statistical analysis revealed significant differences within the groups as well as between the groups following the intervention period.

In Group A, the pre-intervention mean AMAS total score was 35.1 ± 3.45. The mean VABS communication score was 58.1 ± 6.54, daily living score was 56.0 ± 6.40, and the mean 6-Minute Walk Test (6MWT) distance was 315.8 ± 4.28. Salivary biomarker values before intervention showed α-amylase levels of 229.9 ± 8.37, cortisol levels of 0.8 ± 0.04, and serotonin levels of 59.1 ± 3.40. Following the intervention, Group A demonstrated substantial improvement. The AMAS total score increased to 45.3 ± 2.87, VABS communication improved to 68.6 ± 4.76, daily living improved to 69.1 ± 6.86, and 6MWT performance increased to 369.8 ± 3.83. In addition, α-amylase levels decreased to 155.7 ± 7.55 and cortisol levels decreased to 0.5 ± 0.03, while serotonin levels increased to 94.3 ± 3.73. These findings indicate a significant improvement within Group A after the intervention.

In Group B, the pre-intervention mean AMAS total score was 34.6 ± 3.34. The VABS communication score was 59.3 ± 6.43, daily living score was 57.0 ± 6.40, and the 6MWT distance was 318.8 ± 1.76. Salivary biomarker values before intervention included α-amylase at 227.1 ± 7.75, cortisol at 0.8 ± 0.04, and serotonin at 61.3 ± 3.11. After intervention, improvements were also observed in Group B. The AMAS total score increased to 39.2 ± 3.46, VABS communication increased to 62.8 ± 5.41, daily living improved to 62.8 ± 5.94, and the 6MWT distance increased to 343.1 ± 1.78. Salivary α-amylase decreased to 197.6 ± 7.40, cortisol decreased to 0.7 ± 0.03, and serotonin increased to 79.5 ± 3.75. These results indicate significant improvement within Group B as well.

Post-test comparison between Group A and Group B revealed statistically significant differences in AMAS, VABS, salivary biomarkers, 6MWT, and Child Sensory Profile scores. The findings support the alternative hypothesis, showing that Group A achieved greater improvement than Group B across all outcome measures.

DISCUSSION

According to M. Yavuz, teaching occupational skills to people with autism spectrum disorder through direct instruction via augmented reality was quite successful. The desired abilities were successfully acquired by the participants, who were able to apply them when working with different instructors and retain them over time. This implies that the learning was both successful and situation-adaptive. Positive comments from teachers also supported the approach's social relevance and practical utility. Overall, the study indicates that augmented reality-based teaching methods are beneficial in special education settings because they can enhance functional performance and skill acquisition in people with ASD.

Manju and associates discovered that children with ASD benefited from a virtual reality-based treatment program in terms of attention, social interaction, emotional reactions, and decision-making skills. Children were able to progressively graduate from basic attention tasks based on sensory input to more complex activities including communication, social interaction, and decision-making thanks to the multi-level virtual environment. In addition to allowing researchers see emotional responses like worry, annoyance, and exhilaration during various tasks, repeated practice in the virtual reality environment seems to increase engagement and learning. These results suggest that virtual reality (VR) can provide a secure, organized, and productive setting for fostering critical developmental abilities in kids with autism.

Children with ASD may benefit from collaborative virtual settings to enhance their collaboration and communication abilities, according to H. Zhao and colleagues. Their "Hand-in-Hand" technology promoted more organic social engagement with classmates by enabling youngsters to communicate in real time through gestures, gaze, and voice-based features. According to the study, cooperative behavior during play activities improved, and both typically developing children and children with ASD responded well to the approach. These findings suggest that VR-based collaborative systems could be an accessible, entertaining, and reasonably priced means of helping autistic youngsters with their social and communication abilities.

The current study contrasted traditional physiotherapy with VR and AR-based rehabilitation for kids with ASD. The youngsters who took part in the VR and AR-based program made more progress overall than those who just got traditional physiotherapy, even though both treatment modalities significantly improved the assessed outcomes.

Group A showed significant gains in the behavioral, functional, physiological, and sensory areas, according to within-group analysis. Improved motor and functional performance was reflected in the AMAS total score, which increased significantly from 35.1 ± 3.45 to 45.3 ± 2.87 ($t = -17.703$, $p < 0.001$). Communication increased from 58.1 ± 6.54 to 68.6 ± 4.76 ($p < 0.001$), daily living skills from 56.0 ± 6.40 to 69.1 ± 6.86 ($p < 0.001$), and social functioning from 54.6 ± 7.05 to 67.2 ± 6.35 ($p < 0.001$). These modifications point to significant improvements in functional engagement and independence. The 6MWT showed a significant increase in physical endurance from 315.8 ± 4.28 to 369.8 ± 3.83 ($p < 0.001$), indicating better gross motor capacity.

Physiological indicators provided additional evidence of the VR/AR intervention's efficacy. Stress-related biomarker α-amylase dropped from 229.9 ± 8.37 to 155.7 ± 7.55 ($p < 0.001$), cortisol levels dropped from 0.8 ± 0.04 to 0.5 ± 0.03 ($p < 0.001$), and serotonin levels significantly increased from 59.1 ± 3.40 to 94.3 3.73 ($p < 0.001$), indicating better neurochemical balance and emotional regulation. Additionally, all sensory domains—auditory (32.8 to 22.8), visual (29.6 to 21.8), tactile (46.4 to 33.4), and movement processing (32.9 to 23.6)—showed consistent decreases in Child Sensory Profile scores, all with $p < 0.001$, showing greater sensory integration.

Group B, on the other hand, also showed statistically significant improvements, but to a lesser extent. The overall AMAS score increased to 39.2 ± 3.46 ($p < 0.001$) from 34.6 ± 3.34. The VABS domains revealed moderate improvements in everyday living (57.0 to 62.8, $p < 0.001$), social interaction (55.6 to 59.9, $p < 0.001$), and communication (59.3 to 62.8, $p = 0.006$). Although less noticeable, biomarker alterations were also significant: serotonin increased from 61.3 to 79.5 ($p < 0.001$) and α-amylase decreased from 227.1 to 197.6. In the 6MWT, functional capacity increased to 343.1 ± 1.78 from 318.8 ± 1.76 ($p < 0.001$).

Between-group post-intervention comparisons confirmed the superiority of VR/AR-based training. Group A outperformed Group B in AMAS total scores (45.3 ± 2.87 vs 39.2 ± 3.46, $p < 0.001$), VABS communication (68.6 vs 62.8, $p = 0.010$), daily living (69.1 vs 62.8, $p = 0.024$), and social functioning (67.2 vs 59.9, $p = 0.012$). Physiological outcomes also favored Group A, with significantly lower α-amylase (155.7 vs 197.6, $p < 0.001$), lower cortisol (0.5 vs 0.7, $p < 0.001$), and higher serotonin levels (94.3 vs 79.5, $p < 0.001$). Functional endurance was significantly better in Group A as evidenced by higher 6MWT scores (369.8 vs 343.1, $p < 0.001$).

Similarly, sensory processing outcomes showed greater improvement in Group A across all domains, including auditory (22.8 vs 28.6), visual (21.8 vs 25.6), tactile (33.4 vs 40.3), movement (23.6 vs 28.4), and social-emotional processing (41.2 vs 48.8), all favoring VR/AR intervention with statistically significant differences ($p < 0.001$).

In comparison to traditional therapy, the results indicate that immersive VR/AR-based rehabilitation improves multisensory engagement, motivation, and task repetition, all of which may lead to better neuroplastic adaption. Reduced physiological arousal and better emotional regulation are further shown by the observed changes in biochemical stress indicators. Due to their higher efficacy in enhancing functional and sensory outcomes, these findings suggest the integration of immersive technology into pediatric neurorehabilitation programs for children with ASD.

CONCLUSION

The current study found that in children with autism spectrum disorder, sensorimotor abilities, adaptive behavior, sensory processing, functional endurance, and salivary biomarkers were all improved by both VR/AR-based rehabilitation and traditional physiotherapy. Nonetheless, compared to the group receiving traditional physiotherapy, the VR/AR group's improvements were noticeably higher.

When compared to children who received traditional physiotherapy, children who engaged in VR- and AR-based rehabilitation showed higher improvements in AMAS, VABS, Child Sensory Profile scores, salivary biomarkers, and 6-Minute Walk Test performance. According to these findings, children with autism spectrum disorder may benefit more from immersive rehabilitation techniques in terms of increasing their motor skills, sensory processing, and behavioral functions.\These results suggest that VR and AR-based therapies could be a valuable supplement or potential substitute for traditional physiotherapy in pediatric neurorehabilitation programs for children with ASD.

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