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Pediatric Rehabilitation For Children With Cerebral Palsy Through Personalized Vibration Therapy Powered By Artificial Intelligence: An Innovative Approach To Reduce Spasticity And Improved Motor Function And Quality Of Life

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ABSTRACT

Background:*This study explores the integration of AI-IoT in vibration treatment to improve personalized care for patients. Vibration treatment stimulates the body's stretch reflex, reducing muscle stiffness and improving motor function. The aim is to enhance the effectiveness of this treatment.****Objective:*** *The study aimed to explore personalized artificial intelligence-powered vibration therapy for pediatric cerebral palsy rehabilitation, aiming to reduce spasticity, enhance motor function, and enhance quality of life.* ***Methods:*** *The study compared AI-enhanced vibration therapy to conventional exercise therapy using a randomized controlled trial (RCT).[1] Participants were randomly assigned to either the AI-driven vibration therapy group or the control group, receiving regular exercise therapy. The ESP32 Microcontroller system evaluated ECG electrode data to modify vibration therapy parameters in real-time.* ***Results:*** *The study found significant differences in pre-post GMFM (Gross Motor Function Measure) symptoms between groups A and B. Group A showed a mean difference of -5.076, pre-post social well-being of -4.230, pre-post participation and health of -4.076, pre-post pain and impact of disability of 4.538, and pre-post pain and impact of disability of 2.07.****Conclusion:****The study compared AI-enhanced vibration therapy and traditional exercise therapy, finding AI-driven methods significantly reduced spasticity, improved motor function, and improved quality of life compared to the exercise-only control group.*

Keywords: *Artificial Intelligence, Vibration Therapy, Cerebral Palsy, Pediatric Rehabilitation, Muscle Spasticity, ECG Electrodes, ESP32 Microcontroller.*

INTRODUCTION

Cerebral palsy (CP) is a common cause of motor disorders in children, affecting 1.5–3% of live births. It impairs gross motor function, leading to problems with walking, coordination, and musculoskeletal function. The condition is often identified between the ages of 2 and 5, and children with CP reach 90% of their motor development potential by the age of 5

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years or younger.

Cerebral palsy can be classified according to various factors such as motor disturbance type, affected extremity, and brain lesion location. Spasticity is one of the main contributing factors to movement dysfunction in individuals with CP. Other factors include inadequate muscle strength and poor balance control. Muscle atrophy and weakening are increasing, which may lead to myogenic and occasionally arthrogenic contractures in several upper and lower extremity joints.

Speech is among the fine and gross motor capabilities impacted by cerebral palsy. The most common antigravity muscle has comparatively higher muscle tonality than other muscles, making it difficult to control voluntary movements. Poor quality and lack of smoothness in movements are caused by an imbalance in the muscles' strength. Additionally, there has been a delayed start to muscle activation, disrupting proprioceptive feedback to higher centers.

Vibration therapy for neurological issues has grown in popularity over the past 20 years as a rehabilitation tool. Brain stimulation was achieved using focused vibrations (FV) and whole body vibrations (WBV). According to the neurotransmission cognitive theory (NCT), people suffering from neurological disorders can benefit from focused ultra-low frequency vibration waves (8–12 Hz) given to specific body nerve sites. Whole body vibration treatment is a widely used high frequency, low magnitude modality with vibrating platform for increasing physical fitness.

In this research, an assistive model was developed to manage cerebral palsy patients with spasticity through AI-IoT-based vibration therapy for rehabilitation. The model includes four main components: an Arduino board, ECG for measuring electrical activity of muscles, amplifier for power supply, and 9V manual battery. The ESP32 acts as the central hub, collecting data from ECG electrodes and communicating with the computer via a USB connection.

The purpose of this study was pediatric rehabilitation for children with cerebral palsy through personalized vibration therapy powered by artificial intelligence, an innovative approach to reduce spasticity and improve motor function and quality of life.

LITERATRE REVIEW

Peungsuwan et al. (2023) found that static 11 Hz treatment for spasticity and physical performance in children with cerebral palsy reduced spasticity more effectively than a 7-18 Hz WBV program. Stergiou AN, et al. (2023) found that Equine Assisted Therapy (EAT) improved motor function, performance, and spasticity in children with cerebral palsy. Jameel T, et al. (2023) found that Constraint-Induced Movement Therapy (CIMT) improved upper extremity spasticity in children with cerebral palsy. Schafmeyer L, et al. (2023) compared the GMFM-66 and rGMFM-66 in detecting clinically relevant changes in gross motor function in children with cerebral palsy. Sloane BM, et al. (2023) found that caregivers of children in GMFCS level V observed similar benefits and barriers to those in other GMFCS levels. Kaelin VC, et al. (2021) explored the use of Artificial Intelligence in paediatric rehabilitation, addressing three main areas: deficiency in AI-delivered remotely participation-focused interventions, lack of individual goal-setting, and need for customized interventions. Darko Hercog, et al. (2023) explored the design and implementation of ESP32-based IoT devices.

AIM AND OBJECTIVE

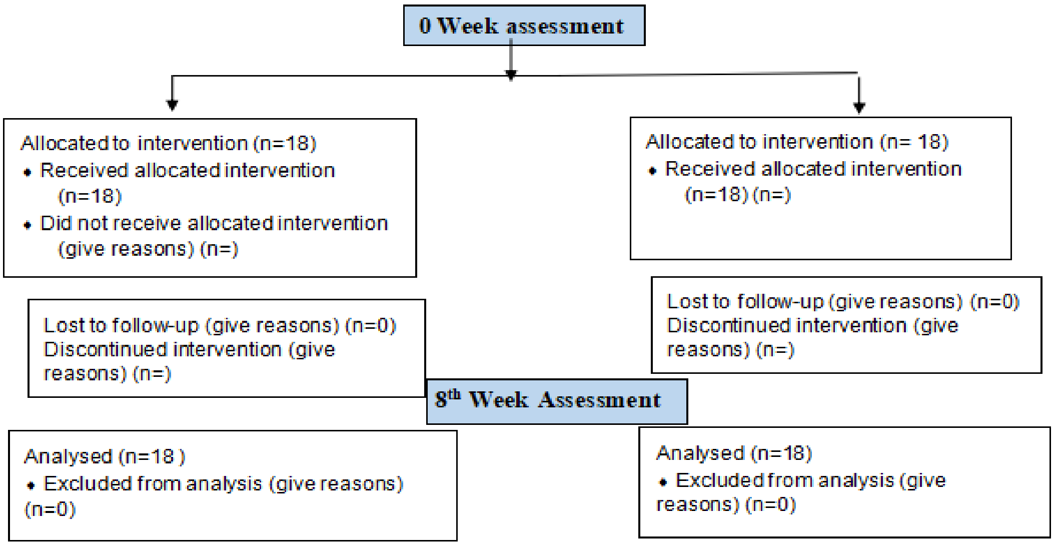
The study aimed to explore personalized artificial intelligence-powered vibration therapy for pediatric cerebral palsy rehabilitation, aiming to reduce spasticity, enhance motor function, and improve quality of life.

MATERIAL AND METHODOLOGY:

The study was a randomized clinical trial conducted in Lahore, with 32 participants from Ali Fatima hospital and Johar pain relief center. The study was conducted over 9 months after approval of synopsis. The sample size was calculated using G-power software, with each group having 18 participants and a 10% attrition rate. The sample was collected using non-probability convenient sampling.

The study's sample selection criteria include children aged 2-9 years with spastic CP, ability to withstand vibrating devices, and no planned surgery within 5 months. Exclusion criteria include a bone fracture within 12 weeks, history of using anabolic agents, glucocorticoids, growth hormone, botulinum toxin injections, or history of illness or physical examination that might prevent completion of the study.

The study used an AI-powered vibration therapy device, an ESP32 microcontroller, ECG electrodes, an amplifier, and a 9V battery for data collection and communication. A user interface was designed to provide real-time data and control over the device. The Gross Motor Function Classification System (GMFCS) was used to distinguish between children with cerebral palsy based on their current gross motor ability, limits, and need for wheeled mobility and assistive technology. The Cerebral Palsy Quality of Life for Children (CP QOL-Child) was the first health condition-specific questionnaire specifically designed to measure QOL in children with cerebral palsy. The Turkish version of the CP QOL questionnaire was found to be a valid and dependable method for assessing children with cerebral palsy.The data was analyzed using SPSS version 20, with normality tests and parametric or non-parametric tests applied. Parametric tests included independent t and paired t tests, while non-parametric tests used Mann Whitney and Wilcoxon tests.



TREATMENT PROTOCOL:

The study involved a population of spastic diplegic CP aged 2 to 9 years.. Participants were divided into two groups based on inclusion and exclusion criteria. Group A received personalized vibration therapy powered by AI, with a target frequency of either 20 Hz or 25 Hz and an amplitude of 2–4 mm. The treatment session was around 20 minutes, with a hot pack as a baseline treatment. The treatment consisted of 6 sessions per week for 8 weeks. The protocol for the massage included setting up ECG electrodes and amplifiers, connecting ECG sensors to the microcontroller, and writing a Python script to interface with the microcontroller and read ECG data. Data was stored in CSV files for further analysis. The Python script generated CSV files and graphs for each data collection phase, analyzing the effectiveness of the massage in terms of muscle activation and relaxation.

A machine learning model was trained, saved, and preprocessed the data. A graphical user interface (GUI) was created for user interaction and used the trained model to provide real-time predictions. Group B received a selected physical therapy treatment program for spastic diplegic CP, assessed by modified Ashworth scale, Gross Motor Function Classification System, and cerebral palsy-Quality of life-child Questionnaire. Pre and post treatment values were measured at baseline and after 8 weeks of treatment sessions. Data was analyzed using SPSS .

RESULTS

The study aimed to determine the distribution of the participants' physical and mental health before and after treatment for a disability. The mean age of the participants was 4.6, while the mean age of the participants in group B was 5.3. The data was analyzed using the Shapiro-Wilk and Kolmogorov-Smirnov tests to determine the normality of the data.

The Wilcoxon within Group Analysis test was applied to the baseline values of group A and group B, comparing them on pre- and post-treatment values. The results showed that the pre-spasticity mean rank in group A was 4.538, and post-spasticity mean rank was 2.461, p-value was 0.01 and z value was -3.50. In group B, the pre-spasticity mean rank was 4.76, and post-spasticity mean rank was 3.76, p-value was 0.01 and z value was -3.606.The Mann-Whitney Test was applied to the baseline values of group A and group B, comparing them on pre- and post-treatment values. The results showed significant improvements in the mean scores, standard deviations, mean differences, and p-values for variables in both groups.

The Mann-Whitney Test was used to compare baseline values of group A and group B on pre-post treatment. Results showed that group A had a mean spasticity rank of 12.73, while group B had a mean rank of 16.15. Post-treatment, group A had a mean spasticity rank of 9.85, while group B had a mean rank of 14.27.

Table 1 Mann Whitney between Group Analyses

Variables	Groups	Mean R	Z-value	P-value	IRQ
Pre-SPASTICITY	Group:1	12.73	-0.531	0.596	5.00
	Group:2	16.15			
Post-SPASTICITY	Group:1	9.85	-2.497	0.013	3.00
	Group:2	14.27			

Paired T Test within Group Analysis summarizes the mean scores, standard deviations, mean differences, and p-values for variables in two groups before and after treatment. The results show significant improvements in GMFM, social well-being, participation and health, and pain and impact of disability. In group B, the mean scores increased from 75.23 to 77.84, with a significant difference of -2.76. The mean scores decreased from 5.23 to 3.15, indicating a reduction in disability level. Results showed significant improvement in GMFM, social well-being, participation and health, and pain and disability impact, with a decrease in disability level and a significant improvement in social well-being.

INDEPENDENT T Test between Groups Analysis for Pre and post Value is done.

For group A, the mean score increased from 75.23 to 80.30, with a difference of -5.076, indicating a significant improvement.

For group B, the mean score increased from 3.000 to 5.23, with a difference of -2.23, indicating a significant improvement.

Table 2 INDEPENDENT T Test between Groups Analysis (Pre-Value)

Variables	Treatment	Mean	St. deviation	Mean Difference	P value
Pre-Treatment GMFM	Group A	75.2308	3.08636	.153	.904
	Group B	75.0769	3.32820		
Pre Social Well Being	Group A	3.5385	1.39137	.769	.176
	Group B	2.7692	1.42325		
Pre Participation And Health	Group A	3.6923	1.54837	.692	.218
	Group B	3.0000	1.22474		
Pre Pain And Impact Of Disability	Group A	7.6154	1.04391	2.384	.892
	Group B	5.2308	1.01274		

The p-values and a summary of the pre-treatment comparisons between Group A and Group B were also provided. Group A had a higher GMFM (Mean ± SD) and a higher social well-being (Mean ± SD), while Group B had a slightly lower improvement. Pre-participation and health showed significant differences between the two groups,
with Group A showing a higher improvement and Group B showing a slightly lower improvement.

Table 3 Independent T Test between Group Analyses (Post-Values)

Variables	Treatment	Mean	St. deviation	Mean Difference	P value
Post Treatment GMFM	Group A	80.3077	3.30113	2.461	.074
	Group B	77.8462	3.41189		
Post Social Well Being	Group A	7.7692	1.09193	2.615	.001
	Group B	5.1538	1.14354		
Post Participation And Health	Group A	7.7692	1.09193	2.538	.001
	Group B	5.2308	.92681		
Post Pain And Impact Of Disability	Group A	3.0769	1.49786	-.0769	.001
	Group B	3.1538	1.34450		

In conclusion, the study demonstrated that the participants' physical and mental health before and after treatment showed significant improvements in their physical and mental health.

DISCUSSION

This study aimed to measure the outcomes of spasticity, gross motor function, and quality of life in children with cerebral palsy through AI-IoT based vibration therapy. The study utilized Artificial Intelligence (AI) to receive data from various sensors and classify them intelligently, generating commands via Internet of Things (IoT) for rehabilitation and support with the help of caretakers for cerebral palsy children. Whole body vibration was used to activate the body's natural stretch reflex, which in turn triggers muscular contractions. The primary ends of the muscle spindle Ia afferent were stimulated by muscular vibration, leading to the excitation of alpha motor neurons and subsequent contractions of motor units, ultimately producing a tonic muscle contraction. Spasticity was measured using an AI-IoT-based measuring device, gross motor function by GMFCS level, and quality of life by the Cerebral palsy-Quality of life-child Questionnaire.

Previous studies have demonstrated that vibration therapy can improve neuromuscular performance by boosting neural drive and enhancing motor control. Another study found that vibration therapy could decrease spasticity, which is essential for children with cerebral palsy to have full mobility and independence. The present study supports these findings, as it shows that better physical comfort, less spasticity, and more muscle function are likely the causes of QoL improvements.

One key finding of the study is how vibration therapy affects gross motor function, which is essential for children with cerebral palsy to have full mobility and independence. The results of this randomized controlled study (RCT) demonstrate that when combined with real-time ECG monitoring, vibration therapy dramatically increases muscular activation and decreases muscle stiffness in children with cerebral palsy. In addition to more conventional physical treatment techniques, vibration therapy seems to provide a fresh and successful intervention.

AI-driven tailored interventions can greatly enhance therapeutic outcomes by customizing therapies to each patient's needs. AI systems can dynamically modify therapy parameters by analyzing intricate data patterns from real-time monitoring. Machine learning models can forecast the best vibration frequencies and intensities based on individual reactions.

The advantages of IoT in monitoring therapeutic interventions were emphasized by A. Girgis et al., who showed how real-time data collecting enhances treatment outcomes by enabling adaptive and responsive care. The incorporation of Internet of Things (IoT) technology, like the ESP32 microcontroller, makes real-time monitoring and data collection easier. Data-driven techniques can provide a more nuanced knowledge of treatment impacts, which can greatly improve therapeutic accuracy and efficacy. When AI and IoT technologies are combined, big data can be analyzed to understand how each patient responds to treatment.

The current study showed massive outcome results by incorporating real-time ECG monitoring via the ESP32 microcontroller, allowing therapy parameters to be precisely adjusted with real-time input, allowing the intervention to be customized to the needs of the patient.

LIMITATIONS:

The study has limitations such as hardware constraints, signal accuracy constraints, and generalizability constraints, as well as being a single-blinded study.

RECOMMENDATIONS:

Researchers should update and refine the device based on user feedback and technological advancements, and clinicians should incorporate this technology for better results in children beyond cerebral palsy.

CONCLUSION:

The study revealed that AI-powered vibration therapy treatment group A showed significant improvements in spasticity, gross motor function and quality of life as compared to control group B.

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