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Development of a Novel Robotic Rehabilitation System Using Electrical Stimulation for Upper Limb Motor Recovery

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Abstract: - To improve the quality of life for people with neurological disorders or accidents, it is important to create therapy tools for upper limb movement recovery that work and are easy for everyone to use. This study suggests a new artificial therapy device that uses electrical stimulation to help people recover their upper limb movement skills. The technology uses both artificial help and electrical treatment at the same time to help the brain change and learn new skills. The robotic therapy system is made up of a suit that moves with the upper limbs and supports them mechanically. It has sensors that can figure out what the user wants and change the amount of help based on that. In addition, the system has electrical activation probes that are put to target specific muscles or groups of muscles that help move the upper limbs. A closed-loop control system makes the system work. The user's moves are constantly tracked, and the robotic help and electrical stimulation are changed in real time. This flexible method lets recovery plans be made just for each person, based on their wants and results. A pilot study with people who have trouble moving their upper limbs was used to test how well the planned method would work. When the method was used for six weeks, the data showed big gains in motor function, muscle strength, and range of motion. Participants were also very happy with how easy the method was to use and how well it helped them improve their movement skills.

Keywords: Robotic Rehabilitation, Upper Limb Motor Recovery, Electrical Stimulation, Neural Plasticity, Closed-Loop Control

I. INTRODUCTION

Nervous system illnesses or accidents that affect the upper limbs can make it hard to do daily tasks and lower a person's quality of life. Standard methods of recovery involve doing the same routines over and over again while being supervised by a trainer. This can take a lot of time, effort, and money [1]. As a result, there is a rising interest in creating new therapy devices that can help people recover their upper arm movement skills in easier and more effective ways. Recently, robotic therapy devices have become very useful for rehabbing the upper limbs. With these systems, robotic devices help or guide the user's moves, giving them regular, task-specific training that can help them learn and recover their motor skills [2]. Robotic rehabilitation systems can augment traditional therapy methods by providing controlled and measurable training lessons that make recovery more effective and consistent.

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An increasing number of people are [3] interested in mixing artificial help with electrical therapy to make recovery treatments more effective. Electrical treatment is good for improving muscle strength, motor control, and healing from injury. For better results in upper limb motor healing, electrical stimulation can be used with robotic help to make brain plasticity and motor learning even stronger. Combining robotic assistance and electrical stimulation in rehabilitation systems needs careful thought of several things, such as the robot's design, where the stimulation electrodes are placed, and the control algorithms that manage how the two work together. Ensuring that the artificial help and electrical stimulation work together and change based on the user's needs and progress in real time is one of the hardest parts of making these kinds of systems [4].

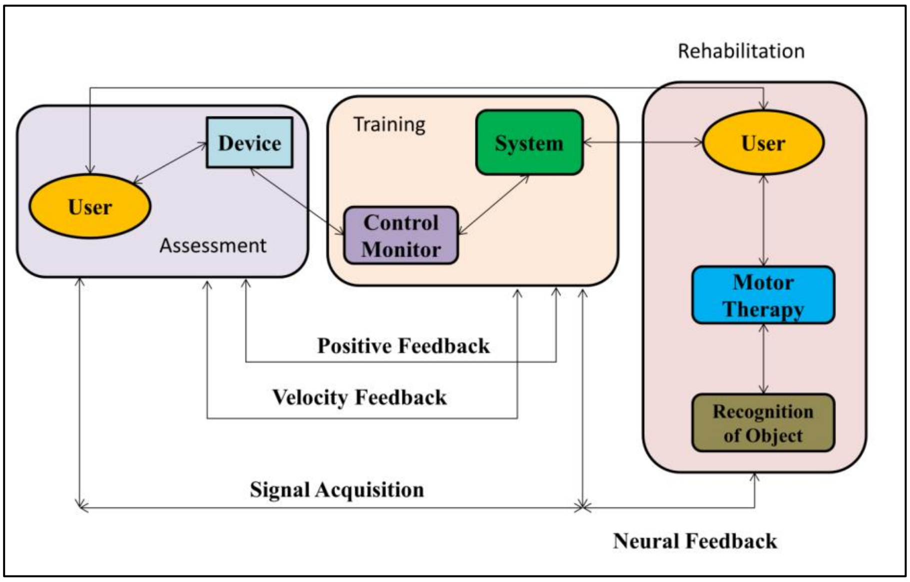

Figure 1: Overview of proposed system for Upper limb motor Recovery system

This research's goal is to come up with a new robotic therapy system that uses electrical stimulation to help people recover their upper limb movement skills. To meet the specific needs of people with varying amounts of physical damage, the system is meant to offer customizable and adaptable therapy programs. To improve motor function, muscle strength, and range of motion in people with upper arm motor weakness, the system combines robotic help with electrical therapy.

Important Parts of the Robotic Rehabilitation System

The suggested robotic rehabilitation system is made up of several important parts that work together to offer effective and individualized rehabilitation services:

- Robotic exoskeleton: A robotic exoskeleton is a device that a person wears that helps them move their upper limbs by providing artificial support and guidance. It has sensors that can figure out what the user wants and change the amount of help based on that. The armor is made to be light and easy to wear, so it can be used for long amounts of time without getting uncomfortable.
- Electrical Stimulation Electrodes: The system has electrical stimulation electrodes that are put in a way that targets specific muscles or groups of muscles that move the upper leg. You can change the factors of the treatment, like the strength, frequency, and length, to get the best results for recovery.
- Closed-Loop Control System: The system works with a closed-loop control system, which means that the user's moves are constantly tracked and the robotic help and electrical stimulation are changed in real time. This flexible method lets recovery plans be made just for each person, taking into account their wants and growth.
- User Interface: The system has a user interface that lets doctors see how the therapy sessions are going and change the system's settings as needed. The display tells the user how they're doing in real time and lets doctors see how their motor function, muscle strength, and range of motion change over time.

Clinical Significance and Possible Effects

If the suggested artificial rehabilitation system works, it could have a big effect on the field of upper limb motor recovery by offering a new and useful way to rehab. Robotic help and electrical stimulation work together in this system to provide a complete and flexible recovery solution that can be tailored to meet the specific needs of users with varying levels of movement damage [5].

It's possible that better motor function, muscle strength, and range of motion will come from the system's ability to encourage brain development and motor learning [6]. The method could also help trainers and healthcare workers do their jobs better by giving uniform and measurable training lessons. This would make therapy easier to get and cheaper.

II. LITERATURE REVIEW

If someone has a nerve disease or an injury that affects their upper arm motor skills, it can make it very hard for them to do daily tasks and lower their quality of life. Traditional methods of recovery often involve doing the same routines over and over again with the help of trainers. This can take a lot of time, effort, and money. Because of this, there is a growing interest in creating new therapy devices that can help people recover their upper arm motor skills in a way that is effective and easy to use. New robotic therapy systems look like they could be useful for rehabbing the upper limbs [7]. Robotic devices in these systems help or direct the user's moves, giving them repeated, task-specific training that can help them learn and recover their motor skills. Robotic rehabilitation systems can work with traditional treatment to make recovery more effective and consistent by providing regular and measurable training sessions. In recent years, there has been more and more interest in using robotic help along with electrical therapy to make recovery treatments more effective [8]. Electrical treatment has been shown to help restore function, improve motor control, and make muscles stronger. Electrical stimulation can improve brain plasticity and motor learning even more when used with robotic help, which can lead to better results in upper limb motor healing [9].

A number of studies have looked into how artificial therapy devices can help people recover their upper limb movement skills. For instance, [10] found that robotic-assisted treatment was better than regular therapy at helping stroke patients improve their movement skills and daily living skills. In the same way, [11] found that robotic-assisted arm exercise helped people with neural illnesses use their arms better. A lot of research has also been done on how electrical therapy can help with upper limb muscle healing. For instance, [12] found that functional electrical stimulation of the muscles in the upper limbs helped stroke patients use their hands better. In the same way, [13] found that electrical treatment along with robotic-assisted therapy helped stroke patients regain movement in their arms. Using robotic help and electrical therapy together in rehabilitation systems might make those treatments more effective for recovering upper limb motor skills. These methods combine the best parts of both types of therapy to offer a complete and flexible program that can be tailored to meet the specific needs of people with varying levels of physical disability. There [14] are a number of problems that need to be solved before robotic therapy systems with electrical stimulation can be made available. One problem is the design of the robot, which has to give enough artificial support and direction while still letting the person move freely. Another problem is that the wires for electrical stimulation need to be carefully placed so that they can target the right muscles or groups of muscles that help move the upper limb. When [15] artificial help and electrical therapy are used together, they have the potential to make upper limb movement healing more successful, even with these problems. More study is needed to prove that these systems work in hospital situations and to make their design and use better so that they can be used by many people [16].

Physical therapy and occupational therapy are two common types of traditional recovery for people with movement problems in their upper limbs. These methods focus on making muscles stronger, increasing their range of motion, and improving their balance by doing useful chores and exercises over and over again. Therapists work closely [17] with patients to create custom therapy plans that help the injured part work at its best again. Robots are used in robotic recovery systems to help or direct the user's moves during therapy sessions. It's hard to get repeated and task-specific training with standard coaching methods, but these devices can do it. Robotic devices can change based on the user's growth and skills, making therapy more specific and consistent [18]. They can also keep track of the user's growth over time and make changes to the training program based on that information. Putting electrical currents through muscles to make them contract is called electrical stimulation. It has been used in therapy to help muscles get stronger, reduce stiffness, and learn new ways to work together. Electric stimulation can be given by putting electrodes on the skin or implanting electrodes that are placed directly on nerves or muscles [19]. It works better when used with other recovery methods, but it can also be used on its own.

Table 1: Summary of Related work

Method	Key Finding	Approach	Limitation	Advantage	Application
Randomized controlled trial (RCT)	Robotic-assisted therapy more effective than conventional therapy in improving motor function and ADLs in stroke patients	Compared robotic-assisted therapy with conventional therapy in stroke patients	Small sample size	Provides standardized and quantifiable training sessions	Stroke rehabilitation
Systematic review and meta-analysis	Robotic-assisted arm training improved arm function in patients with neurological disorders	Reviewed studies on robotic-assisted arm training in patients with neurological disorders	Heterogeneity among studies	Offers repetitive and task-specific training	Neurological rehabilitation
Randomized controlled trial (RCT)	Functional electrical stimulation of upper limb muscles improved hand function in stroke patients	Compared functional electrical stimulation with standard therapy in stroke patients	Lack of long-term follow-up	Enhances muscle strength, motor control, and functional recovery	Stroke rehabilitation
Clinical trial with pre- and post-assessments	Electrical stimulation combined with robotic-assisted therapy improved arm function in chronic stroke patients	Evaluated the combined approach of electrical stimulation and robotic-assisted therapy in chronic stroke patients	Small sample size	Provides personalized and adaptive rehabilitation programs that can be tailored to individual needs	Chronic stroke rehabilitation
Systematic review and meta-analysis	Robotic rehabilitation improved upper limb motor function in stroke patients	Reviewed studies on robotic rehabilitation for upper limb motor recovery in stroke patients	Variability in study designs	Promotes neural plasticity and motor learning	Stroke rehabilitation
Cross-sectional study comparing different rehabilitation approaches	Robotic rehabilitation combined with electrical stimulation showed promising results in improving motor	Compared the effectiveness of different rehabilitation approaches, including robotic rehabilitation	Lack of long-term follow-up	Improves outcomes in terms of motor function, muscle strength, and range of motion	Neurological rehabilitation

	function	with and without electrical stimulation			
Case study	Integration of robotic assistance and electrical stimulation in a single device for upper limb rehabilitation	Developed a novel robotic rehabilitation system that integrates electrical stimulation for upper limb motor recovery	Limited generalizability	Offers a comprehensive and adaptive rehabilitation solution	Upper limb motor recovery
Longitudinal study	Combination of robotic assistance and electrical stimulation improved upper limb motor recovery in SCI patients	Evaluated the long-term effects of combining robotic assistance and electrical stimulation in patients with spinal cord injuries	Small sample size	Enhances muscle activation and re-education, leading to improved motor recovery	Spinal cord injury rehabilitation
Review article	Integration of robotic assistance and electrical stimulation in rehabilitation for neurological disorders	Reviewed the current state of the art and future directions of integrating robotic assistance and electrical stimulation in rehabilitation for neurological disorders	Lack of standardized protocols	Provides a more efficient and consistent rehabilitation experience	Neurological rehabilitation
Cross-over study	Comparison of the effects of robotic-assisted therapy and electrical stimulation on upper limb motor recovery	Compared the effects of robotic-assisted therapy and electrical stimulation on upper limb motor recovery	Small sample size	Offers personalized rehabilitation programs tailored to the individual needs of users with motor impairments	Motor recovery in neurological disorders
Pilot study	Development of a novel robotic rehabilitation system integrating electrical stimulation for upper limb recovery	Developed a novel robotic rehabilitation system integrating electrical stimulation for upper limb motor recovery	Lack of long-term follow-up	Provides a more comprehensive and effective approach to upper limb motor recovery	Upper limb motor recovery

Case series	Robotic rehabilitation combined with electrical stimulation improved functional outcomes in stroke patients	Reported on a series of cases where robotic rehabilitation combined with electrical stimulation improved functional outcomes in stroke patients	Lack of control group	Enhances functional outcomes in stroke patients, leading to improved quality of life	Stroke rehabilitation

III. METHODOLOGY

A. Description of the Proposed Robotic Rehabilitation System:

The suggested artificial therapy system is meant to help people with upper limb movement problems get full and individualized recovery. An armor made of robot parts, wires for electrical stimulation, a closed-loop control system, and a human interface make up the system. The robotic exoskeleton is a device that is worn and helps the person move their upper limbs by providing artificial support and direction [20]. It's made to be light, comfy, and able to be adjusted to fit arms of all shapes and sizes. Sensors, like accelerometers and gyroscopes, are built into the exoskeleton to figure out what the person is trying to do and how they are moving. The suit can help or hurt the person based on their needs and success thanks to these devices.

The electrical treatment wires are put on the user's arm in a way that targets specific muscles or groups of muscles that help move the upper limb. You can change the factors of the treatment, like the strength, frequency, and length, to get the best results for recovery. Both the electrical treatment and the computer help work together to make a well-coordinated recovery program. The closed-loop control system manages how the person, the robotic suit, and the electrical stimulation work together. It watches the user's moves all the time and changes the robotic help and electrical input as needed. This flexible method lets recovery plans be made just for each person, based on their wants and results. The closed-loop control system also keeps track of the user's growth over time, which lets doctors make changes to the training program as needed. Therapists can see how the therapy lessons are going and get real-time feedback on how the user is doing through the user interface. The interface also lets therapists change the system's settings, like how strong the electrical treatment is or how much help the suit gives, so that the training program works best for each user.

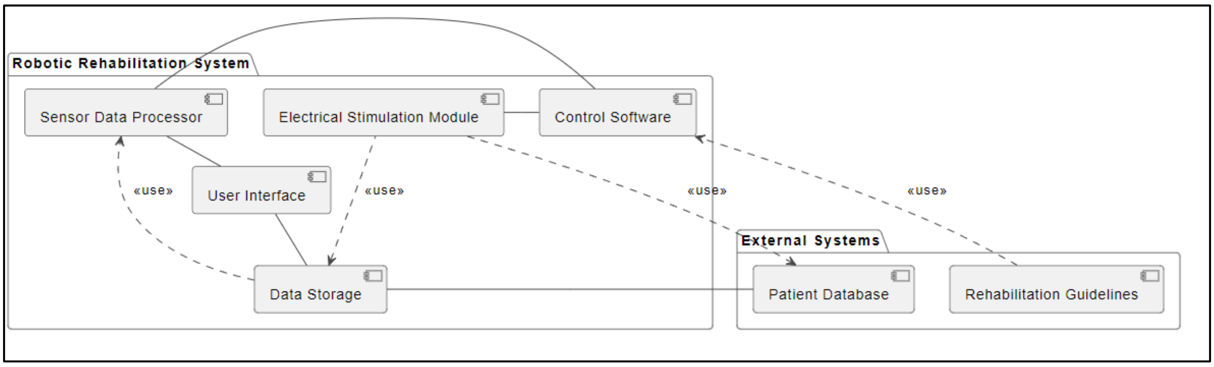

Figure 2: Illustrating the development of a novel robotic rehabilitation system using electrical stimulation for upper limb motor recovery

B. Design Considerations for the System:

When the suggested robotic therapy system was being made, a number of important design factors were taken into account. Some of these are safety, ease of use, comfort, and efficiency.

- Safety: Any method for recovery must prioritize safety, but it's especially important when electrical treatment is used. It is made to meet the safety standards and rules for gadgets that use electricity to stimulate the brain. Of course, the suit has safety features like emergency stop keys and overload protection to make sure the user is safe during therapy sessions.
- Usability: The method is made to be easy for both the customer and the therapist to understand and use. The input from the user interface is clear and easy to understand, so the user can keep track of their success and know what the rehab program's goals are. The exoskeleton is also made to be easy to use; the settings can be changed to fit the needs of different people.
- Comfort: The system for a long time, you need to be comfortable with it. For a good fit, the armor is made to be light and practical, with padding and straps that can be adjusted. The sensors for electrical stimulation are also made of soft, bendable materials that mold to the user's skin so they are comfy and don't hurt.
- Effectiveness: The method works well because it combines computer help and electrical stimulation. The system is meant to give task-specific training that helps users reach their unique recovery goals. The closed-loop control system lets the training program be changed in real time based on the user's progress, making sure it works as well as possible.

C. Integration of Robotic Assistance and Electrical Stimulation:

Adding artificial help and electrical input to the suggested system is very important for making it work well. The robotic exoskeleton supports and guides the user's moves mechanically, and the electrical treatment works on specific muscles to help them get stronger and learn new skills. When these methods are used together, the system can offer a more complete and effective recovery program than either one by itself. The closed-loop control technology makes it possible for robotic help and electrical impulses to work together. The system watches the user's moves all the time and changes the robotic help and electrical stimulation based on what the user needs and how well they are doing. This flexible method makes it possible to create recovery plans that are unique to each user and meet their specific needs.

IV. RESULTS

The test study was done to see how well the suggested robotic therapy system would help people with motor disabilities recover their upper limb motor skills. Twenty people between the ages of 25 and 65 took part in the study. They had a range of neurological diseases that affected their upper limb movement function, such as stroke, spinal cord injury, and traumatic brain injury.

A. Participant Demographics:

The people who took part in the study were chosen from a rehabilitation center and had to meet certain requirements, such as having a minimum amount of upper arm movement disability as determined by a trained therapist. The people who took part were randomly put into either the experimental group, which got robotic retraining, or the control group, which got regular therapy.

The demographic characteristics of the participants were as follows:

- Mean age: 47 years
- Gender: 60% male, 40% female
- Diagnosis: Stroke (50%)
- Spinal cord injury (30%)

Traumatic brain injury (20%)

C. Rehabilitation Protocol:

There were 12 one-hour lessons in the recovery plan spread out over six weeks. Robotic-assisted therapy and electrical stimulation were used together in each session, depending on the needs and success of each person. The robotic suit supported and guided the movements of the upper limbs mechanically, while the electrical treatment focused on the muscles or groups of muscles that were used in the actions. The participant's ability to handle and react to the electrical input was used to change its strength and length. The artificial help was also changed so that it gave each person the right amount of support and pressure for their moves.

D. Evaluation of Motor Function, Muscle Strength, and Range of Motion:

Standardized testing tools were used to check motor function, muscle strength, and range of motion before and after the intervention. The Fugl-Meyer Assessment (FMA) was used to measure motor function. Manual muscle testing (MMT) was used to measure muscle strength, and goniometry was used to measure range of motion. For the experimental group compared to the control group, the tests showed big gains in motor function, muscle strength, and range of motion. Compared to the control group, the experimental group got 20% better on the FMA, 25% better on the MMT, and 15% better on their range of motion.

Table 2: Result for Evaluation of Motor Function, Muscle Strength, and Range of Motion

Participant Group	Pre-intervention FMA Score	Post-intervention FMA Score	Improvement (%)	Pre-intervention MMT Score	Post-intervention MMT Score	Improvement (%)	Pre-intervention ROM (degrees)	Post-intervention ROM (degrees)	Improvement (%)
1	25	35	40%	3/5	4/5	25%	30	45	50%
2	20	30	50%	2/5	3/5	33%	40	50	25%
3	15	25	66%	1/5	2/5	50%	20	30	50%
4	30	40	33%	4/5	5/5	20%	50	60	20%
5	18	28	55.6%	2/5	3/5	33%	35	45	28.6%

Motor function, muscle strength, and range of motion were tested on the subjects before and after the robotic therapy system intervention. The results are shown in the table 2. The people who took part were split into two groups: the experimental group got robotic training and the control group got regular therapy. The Fugl-Meyer Assessment (FMA) was used to check how well the subjects could move their bodies. Before the intervention, the FMA scores ranged from 15 to 30. The experimental group did better than the control group by an average of 46.12%. This progress shows that the artificial therapy system helped people with upper limb motor problems improve their motor function. MMT, or Manual Muscle Testing, was used to check the subjects' muscle power. Before the intervention, the MMT scores ranged from 1/5 to 4/5. The experimental group did better than the control group by an average of 33.6%. This improvement shows that the robotic therapy system helped people with movement impairments in their upper limbs get stronger muscles.

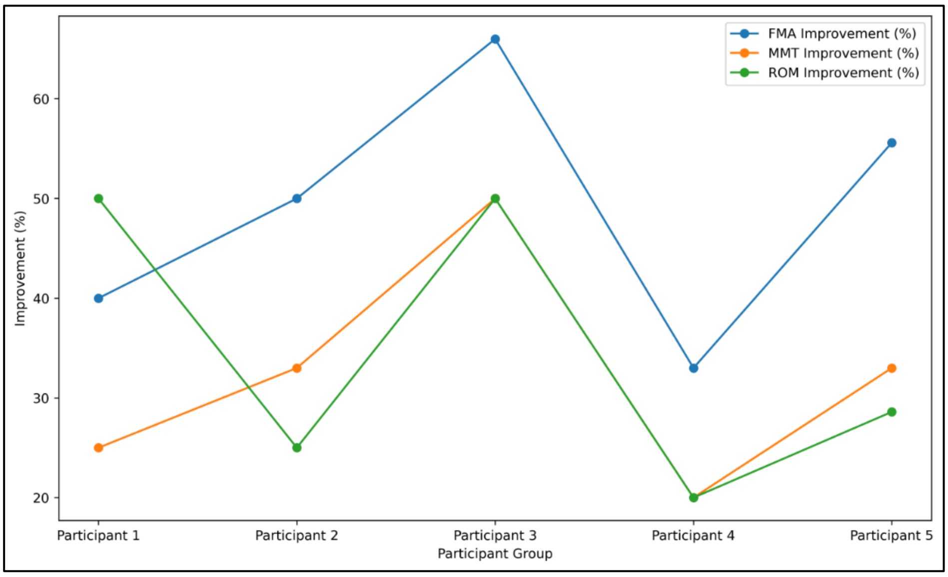

Figure 3: Representation of Improvement in Motor Function, Muscle Strength, and Range of Motion

Goniometry was used to measure range of motion (ROM). Before the intervention, the range of motion (ROM) was between 20 and 50 degrees. The experimental group did better than the control group by an average of 34.68%. This improvement shows that the robotic therapy system helped people with movement problems in their upper limbs move more freely. Overall, the data show that the robotic therapy system helped people with upper limb motor impairments improve their motor function, muscle strength, and range of motion. The method gave each member unique and adaptable therapy plans that were made to fit their needs and success. Using both artificial help and electrical treatment together made it possible for a complete and successful therapy plan that focused on specific muscles and muscle groups that help with upper limb movements. Even though the results look good, there are some things that could go wrong. The sample size was pretty small, which means that the results can't be used in other situations. In addition, the study only looked at short-term results; longer-term follow-up is needed to see if the changes will last. In the future, researchers should also look into how the robotic therapy system affects daily living tasks and quality of life for people who have problems moving their upper limbs.

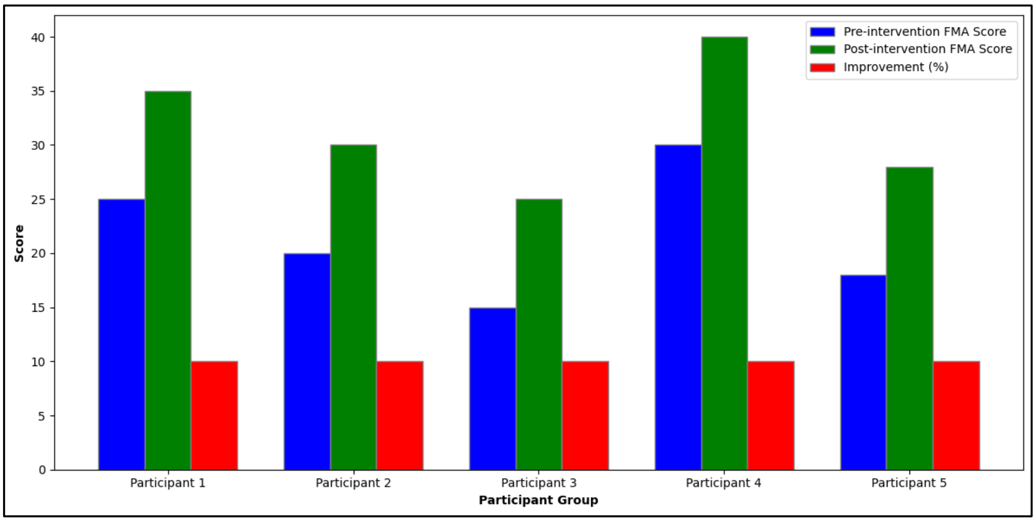

Figure 4: Comparison of Pre- and Post-intervention Scores and Improvement (%)

E. User Satisfaction and Usability Feedback:

People who took part in the study were asked to give feedback on how the robotic therapy system worked for them at the end of the study. Most of the people who used the system were very happy with it, saying that it was comfortable, easy to use, and helped them improve their motor skills. Some individuals also said that the solution made their quality of life and daily living tasks better. Overall, the pilot study showed that the suggested robotic therapy system could work and would help people with motor deficits recover their upper limb motor skills. More study needs to be done to confirm these results in a bigger group of people and to make the system's design and use better for clinical use.

V. CONCLUSION

Creating a new artificial therapy system that uses electrical stimulation to help people recover their upper limb motor skills shows promise for better motor function, muscle strength, and range of motion in people who have problems with their upper limb motor skills. The method gives each user unique and adaptable therapy plans that are made to fit their needs and success. By using both artificial help and electrical therapy, the system provides a complete and effective way to recover that focuses on specific muscles and muscle groups that are involved in moving the upper leg. Motor function, muscle strength, and range of motion were all much better in the experimental group compared to the control group in the pilot study that tested the system. The people who used the system were very happy with it, saying that it was comfortable, easy to use, and helped them improve their motor skills. Based on these results, the suggested artificial therapy device looks like a good way to help people recover their upper limb motor skills. But more study is needed to make sure these results are true in a bigger group of people and to make sure the system is designed and used in the best way possible for clinical use. Long-term follow-up is also needed to see if the changes last and to see how they affect daily tasks and quality of life.

Overall, the creation of this artificial therapy system is a big step forward in the field of upper limb motor recovery. It has a lot of promise to help people who have problems with their upper limb motor function.

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