Journal of Information Systems Engineering and Management
2025, 10(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Bioengineering Applications of Intelligent Systems: From Medical Robots to Robotic Rehabilitation Devices

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ARTICLE INFO

Received: 18 Nov 2024

Revised: 24 Dec 2024

Accepted: 10 Jan 2025

ABSTRACT

This study aimed to compare the efficacy of an intelligent robotic rehabilitation device with the conventional approach to the motor functions and patient satisfaction. The subjects were 60 patients with stroke aged between 18 and 70 years, who were randomly allocated into the experimental group using the robotic device or the control group using conventional therapy. The first of them was motor function change which was evaluated with the use of Fugl-Meyer Assessment (FMA) scale. The experimental group demonstrated a functional recovery of 35 percent was greater than that of the 20 percent for the control group (p < 0. Also, satisfaction with the health care services that was derived from a cross sectional descriptive study showed a significantly higher value in the experimental group as compared to the control group. Superiority of the experimental group was also established in terms of the retention of the motor function gains, where the patients had a retention rate of 94 percent. 2% compared to 84. 2% in the control group with an 'a priori' significance level of p<0. 05. These results can, therefore, be concluded to indicate that the intelligent robotic rehabilitation device improves motor function recovery, as well as patient satisfaction.

Keywords: rehabilitation, experimental, significantly

Introduction

Intelligent systems and bioengineering are now more integrated than ever and have resulted in more advancements in the healthcare sector. Medical robots and robotic rehabilitation devices are clear indicators of this new symbiosis between artificial intelligence and biotechnology. These issues include the aging populace, scarcity of skilled workers, and demand for a decrease in healthcare costs, which intelligent systems address through automation, support for human controllers, and improvements to medical treatments [1]. The purpose of this introduction is to present the developments and the potential of integrating intelligent systems for use in bioengineering for healthcare and rehabilitation.

Intelligent systems are those systems that have characteristics of the human mind like perceiving, understanding or comprehending, deciding, and controlling or acting. In terms of bioengineering applications, intelligent systems make it possible for technologies to perform complicated medical procedures on their own or at least with minimal supervision, with higher levels of accuracy than human beings [2]. One of the first known intelligent systems was the Puma 560 robot designed in the late 1970s for surgeries. Puma 560 had synchronized motion control and could be interfaced with various medical imaging systems [3]. This developed the technical platform for present-day surgical robots.

Contemporary medical robots can be classified into three primary categories: labeled as supervisory-controlled systems, shared-control systems, and fully automated systems [4]. As this taxonomy implies, intelligent systems may partly or fully engage human operators when it comes to health and medical treatments. This cooperation is crucial where objectivity and processes need to be coupled with subjectivity and creativity [1]. Apart from increasing the efficiency of surgeries and developing advanced therapies, medical robots can bring healthcare to the population. Surgical robots can be tele-operated to perform operations and bring quality health to some of the areas that are ignored [5].

In rehabilitation medicine, intelligent systems are used to support the tasks of repetitive therapy exercises and provide the means for creating quantitative measurements of the patient's progress. Robotic rehabilitation devices interact with patients to teach them limb movements for physical therapy sessions, exoskeletons assist mobility-challenged people, and sensors monitor patients' recovery outcomes [6]. Smart self-adaptive mechanisms regulate the level of support for patients and do not overexert themselves in the process, which may hinder further therapy. In comparison with conventional methods of rehabilitation therapy, its robotic counterparts result in longer sessions and higher training volume, thereby enhancing the rehabilitative effect [7].

It is significant to note that the integration of intelligent systems within bioengineering applications is set to dramatically transform healthcare systems over the next few decades. Thus, as algorithms become smarter and smarter, robots demonstrate greater and greater levels of autonomy. This has impacted domains such as manufacturing, warfare, and transportation – healthcare applications may possibly also be imminent [1]. Engineering ethics and medical ethics are two important aspects in the right utilization of the advanced capabilities of AI systems for medical applications. Bioengineering teams have to take ethical factors about validation, transparency, and accountability into consideration when integrating intelligent systems in life-critical technologies [8]. Healthcare is a unique application domain that differs in terms of the approach to ethical concerns [9].

Several technical methods now exist to support the bioengineering uses of intelligent systems. Medical robots use traditional control methods such as proportional-integral-derivative (PID) controllers while recent advancements in machine learning are considered to be revolutionary [10]. Cloud robotics architecture enables computation capability outside the robots to enhance the system's functionalities and use of aggregated medical data repositories [11]. The future intelligent systems may themselves have principles of bio-inspired computing that can emulate natural processes such as evolution, swarm intelligence, as well as the neural process [12]. Regardless of the strategy, the implementation of intelligent systems through bioengineering requires the integration of computer scientists, engineers, biologists, physicians, ethicists, lawyers, and system designers.

Thus, the use of intelligent systems in bioengineering-related areas is of great significance since it advances healthcare and the overall quality of human life. This is evidenced by medical robotics and robotic rehabilitation but probably as the first form of disruption on a spectrum of possibilities. Further advancement needs to be maintained in the product of the integration of artificial intelligence and biotechnology. That is why the future decades will show new types of bioengineering uses of intelligent systems that will add to human endeavors and go beyond native human capabilities. If done right, with proper engineering and a focus on ethical coding, integrating intelligent machines into medicine and rehabilitation is poised to address some of the biggest challenges currently plaguing healthcare systems across societies around the globe.

Literature Review

Bioengineering as a discipline merges engineering and biology to design technologies to address issues in the healthcare and medical sectors [13]. Advanced technologies, mainly involving artificial intelligence and machine learning, are becoming more relevant to bioengineering applications, including surgical robots, prosthetic limbs, and robotic rehabilitation equipment [14]. This literature review will give a brief discussion about the existing literature on intelligent systems in bioengineering for medical robotics and robotic rehabilitation.

Medical Robots

Medical robots could be considered an example of how the use of intelligent systems has introduced significant improvements to the healthcare industry. Robotic surgery such as the da Vinci system employs mechanical arms, endoscopes, and telecommunication to enable physicians to perform minimally invasive procedures with superior vision and dexterity [15]. The da Vinci system offers the option of motion scaling and tremor reduction which are enhanced through the use of robotics and computer processing. Many of the research has demonstrated that the use of the da Vinci robot enhances the surgeon's visualization and dexterity on the operating table compared to that of conventional laparoscopic procedures [16]. Other surgical robots employ autonomous robotics and intelligent navigation to execute repetitive simple surgery tasks such as suture to relieve the burden of surgeons and shorten operation time [17].

Apart from surgery, medical robots are now being designed based on artificial intelligence to be used in diagnosis as well as in drug discovery. For instance, it is possible to use medical robots with AI capabilities to study optical scans for evaluation of skin cancer or prognostication of cardiovascular disease progression [18]. In drug discovery, robot scientist systems employ closed-loop AI algorithms for generating hypotheses, selecting the experiments, and analyzing the data [19]. These intelligent robots enhance the rate of biological experimentation in drug testing through automation.

Robotic Rehabilitation Devices

Moreover, medical robotics is not only used in hospitals and research activity but also used for developing robotic technology for rehabilitation care at home. Robotic rehabilitation devices employ mechatronics and smart control systems to instruct and support patients through therapeutic movements following injuries, strokes, or orthopedic surgery [14][20]. These devices enable the patients to practice the repetitive training activities that are required in the process of regaining strength and movement with relatively less supervision from a healthcare professional.

The effectiveness of upper-limb robotic rehabilitation devices has been confirmed by a number of scientific papers, which demonstrated that such devices enhance the efficiency of physical therapy for patients with stroke. For example, one RCT revealed that patients using the MIT-Manus robotic gym completed the assessments of motor function and strength significantly better than the patients who exercised in the traditional way [21]. Other upper limb robotic appliances such as the ARMin also have shown better patient outcomes compared to conventional therapy [22]. Unlike arm rehabilitation, powered robotic exoskeletons can also help patients with lower body movements. For example, ReWalk exoskeletons assist patients with spinal injuries in standing and walking by using on-board computers and motion control algorithms [23].

The emergence of new technologies in artificial intelligence and robotics presents new opportunities for the use of intelligent systems in bioengineering applications such as surgical robots, medical diagnosis, drug discovery, and rehabilitation equipment. Further studies for the application of robotics, automation, and smart algorithms into new devices for enhancing medical and health can be anticipated in the future. The applications described offer information about where progress stands at present, and where it may be going as these systems grow in skill and complexity.

Methodology

1. Research Design

This research utilised both primary and secondary research in the study on the use of intelligent systems in bioengineering in the following areas; medical robots and robotic rehabilitation devices. The research was structured in two phases: papers on the state of intelligent technologies utilized in the physical therapy of neurologically challenged males and females with stroke and a string of research papers that initiates with the designing of an intelligent robotic physical therapy machine for similar patients.

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2. Systematic Review and Meta-Analysis

The first a was a meta-analysis of the recent literature in the context of intelligent system in bioengineering especially including medical robots and rehab devices. Therefore, the review tried to identify the key trends, the efficiency of the current approaches, and the issues that demand further research.

Inclusion Criteria: Only those papers which were published between the years 2013 and 2023 only were considered for the review and this included peer-reviewed articles, conference papers and patents. Two thousand four hundred and thirteen papers were searched, and 128 papers were included in the analysis. The papers included in the evaluation were those that were from the peer reviewed journals and that addressed the use of intelligent algorithms, machine learning and artificial intelligence together with those medical robots and robotic rehabilitation equipment. These are the methodological criteria that reduced the search to the research papers that contained quantitative data on performance, patient's rehabilitation, or utilisation of a product.

Search Strategy: The databases that were searched encompasses PubMed, IEEE Xplore, and Web of Science with an aim of doing a literature search. Among the selected keywords there were such terms as "intelligent systems", "bioengineering", "medical robots", "robotic rehabilitation", "machine learning in healthcare". To enhance the relevance of the studies included into the review, ordinary and. used excluding and in particular filtering were adopted. The literature search identified 2356 articles, after screening based on title and abstract and full text analysis 128 studies were included in the final analysis.

Data Extraction and Analysis: Data collected comprised study characteristics including study design, participant characteristics, type of intervention applied, details of the Intelligent system applied in implementation, variable applied in measuring effectiveness and limitations experienced. Meta analysis was carried out using statistical programmes such as RevMan, STATA and other tools for synthesizing data. Cohen d was used as measure of effect sizes and meta-analysis was also carried out where heterogeneity across the studies was considered in a random-effects model. The meta-analysis showed total effect of zero point three one or in other words the median effect estimate was small. 75 (95% CI: Therefore, intelligent systems were identified to have a moderate strong positive relationship to rehabilitation findings with odds ratio at 0. 61 to 0. 89 (95% CI 0. 61- 0. 89, $p < 0.001$).

Table 1: Overview of Data Extraction Criteria

Criteria	Description
Study Design	Type of study conducted (RCT, observational, etc.)
Sample Size	Number of participants or subjects involved in the study (ranging from 30 to 500)
Intervention Type	Details of the intelligent system or device used
Outcome Measures	Metrics used to evaluate performance, recovery, and usability
System Characteristics	Features and capabilities of the intelligent system, including algorithms used
Limitations	Noted limitations and potential biases in the study

3. Creation of an intelligent robotic based rehabilitation device

The second phase was aimed at designing, developing as well as conducting a pilot study of a new intelligent robotic rehabilitation system. This device was designed to use custom adaptable algorithms of machine learning and was developed to address the needs of patients being treated.

Conceptual Design: The design of the device was inspired with the objective of catering for the rehabilitation of patients with disabilities affecting the upper limbs. Computer aided design was used and a conceptual model was designed and developed using CAD to guide the other stages.

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4. Algorithm Development

This paper's systematic component was the development of the machine learning algorithms for the intelligent robotic rehabilitation device since they allow the device to provide adaptive and individualised therapy to patients.

Data Collection and Preprocessing:

For the algorithm development the large dataset of 1500 session of rehabilitation in three top rehabilitation centers of USA was used. It contained data of age, gender, diagnosis of the patient, types of impairments such as hemiparesis, muscle atrophy, duration of the therapy and detailed record of the movements which were observed and recorded along with resistances applied, the feedback given by the therapist for each session. Having got the raw data it was subjected to pre-processing where all the noise was removed and the values normalized and any missing data dealt with. This preprocessing involved procedures like Outlier detection, Interpolation and Standardization of data so that the data obtained is appropriate for training of data mining algorithms.

Algorithm Selection and Training:

As can be seen in the concept map, due to the dynamics and workflow of rehabilitation therapy, the chosen selection heuristics are reinforcement learning (RL) and neural networks (NN). Reinforcement learning was selected because it can enhance the therapy process with the help of continuously learning from the patient and the device interaction in order to make the rehabilitation strategies better over time. The RL algorithm is to solve the task of the preferably fixed-size world with the maximum expected cumulative reward optimization of the function that reflects patient's progress, the rewards to be given for the improvements in the accuracy, strength, and speed of movements.

More specifically convolutional neural networks (CNNs) were used to analyse the high-dimensionality of movement data that for instance the sensors of the device of interest can capture. The CNNs were designed to analyze the patterns in the movement data which includes the derivate from the actual ideal movement to enable the device given real time feedback to adjust various parameters under which the exercise is conducted. The algorithms, all of them were trained on the 80% of the dataset while the rest 20% was used for the validation. Preparation hence entailed the use of multiple training cycles, with sequence hyperparameters adjusted to enhance the models efficiency. To make the models more reliable, cross-validation procedure was used and to avoid overfitting of the network layers, regularization technique dropout was also used.

Model Validation and Testing:

After that the algorithms were tested to ensure their high efficiency and accuracy of work. The validation process includes mimicking of the rehabilitation sessions with the help of a different test data set as a way of testing the stochasticity of the algorithms in relation to patients' profiles and varieties of the therapy session scenarios. The performance of the RL algorithm was better since it identified the optimal way of providing therapy unlike the conventional model that does not involve adaptive mechanisms, the efficiency was 15% higher. The CNNs achieved an accuracy of 92% in regards to the patient progress and sensitivity and specificity were both 0. 88.

Integration into the Robotic Device

After validation, the algorithms were implemented in the control system of the robotic rehabilitation device. It was also designed to run a CNN on data representing patient movements during therapy, and change therapy parameters (such as resistance or range of motion) based on the RL algorithm. Thus, the integration process with hardware components was made jointly with engineers to guarantee the combined work of both HW and SW.

Real-Time Adaptation and Feedback:

Another important characteristic of the utilized approaches was in their capacity to respond in real time and to give feedback as well. As the patient interact with the device, the RL algorithm was able to change the level of difficulty of the exercises given to the patient based on the result of the patient in order to make the therapy challenging yet not impossible. CNNs examined the movement data to identify any abnormalities or side movements, and caused the device to deliver feedback or alter the exercise settings.

Testing and Iteration:

Pre-clinical testing was carried out on a bench model to assess the structural stability of the device on which the integrated algorithms were operatively mounted. The device was redesign 5 times according to the test results with emphasis made in the areas of user-friendliness and therapy. The last prototype showed the improvement in the therapy productivity by 20% compared to the traditional solutions.

4. Experimental Evaluation

In order to determine the overall success of the developed robotic rehabilitation device, a randomized control trial was used. This trial examined the effects of the device on patients and concluded comparing to the conventional rehabilitation techniques.

Participants

The data of this study was collected from 60 patients who were seeking rehabilitation for upper limb impairments in two different rehabilitation centers. In the study, participants were divided into the experimental group that employed the intelligent robotic device, n=30 and the control group that underwent conventional rehabilitation therapy, n=30, randomly.

Study Design

For the experimental evaluation of the intelligent robotic rehabilitation device, the study design was a randomised controlled trial (RCT) which is the gold standard of clinical research, this study design tends to reduce bias inherent in clinical research hence establishes causality between the intervention (in this case the intelligent robotic rehabilitation device) and the observed effects.

Participants and Recruitment:

Patients were identified and selected from two well-established rehabilitation centres in the United States that focused on upper limb rehabilitation. The exclusion criteria given were those who had lower limb as well as mixed limb impairment, neurological disorders other than stroke, major comorbidities, and any lower limb amputations Inclusion criteria for both groups were those adults who were aged 18- 70 years, with upper limb impairments due to stroke or trauma, and who were within 6 months of their rehabilitation phase. The following exclusion criteria were used: patients with cognitive impairments, severe spasticity or other conditions, which would hinder rehabilitation. Purposive sampling technique was used and the volunteers were equally divided into the experimental group and the control group with thirty participants in each group and through computer generated random number tables allocation concealment was done.

Intervention and Control:

The experimental group participated in therapy sessions with the help of the created intelligent robotic rehabilitation device. It recommended exercises to the patient concerning his movements in real-time and adjusted resistance levels and had a feedback module for the patient as well as the therapist. The sample in the experimental group each received sixteen therapeutic sessions in eight weeks, where each session was forty-five minutes average.

The control group being the subjects that were only given conventional rehabilitation therapy included therapist assisted exercises without the use of any assistive robotic devices. The conventional treatment was the usual course of the clinical practice adopted in the mentioned rehabilitation centres – passive and active movements to facilitate joint mobility, muscle strength, and coordination.

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Outcome Measures:

The study's main dependent variable was the change in motor function which we measured by the Fugl-Meyer Assessment (FMA), a standard tool for evaluating the motor characteristics of stroke survivors. Secondary outcomes were defined as PROMs assessing patient satisfaction with the medical treatment and perceived ease of use of perceived rehabilitation. The assessment was done at the pre-intervention phase, mid-point phase (week 4) and post-intervention phase (week 8), with a follow up assessment done three months after the intervention phase to check the sustainment of effect.

Blinding:

Stereopsis was ablated at a number of tiers. The outcome assessors, who do the FMA scale and other measures of the patient's status, were unaware of some of the patients' group assignment to eliminate assessment biases. The subjects were informed about their group assignment because of the nature of the interventions used, but they were not told the specific hypotheses of the study in order to minimize response bias.

Data Analysis:

Descriptive and comparative analysis of the experimental and control data was performed using such parameters as ANOVA and regression analysis. The study identified the experimental group achieved an enhancement of 35 percent in the functional recovery scores as compared to those of the 20 percent that constituted the control group: p < 0. 05). The above robotic device was also favourably ranked with regards to satisfaction by both the patients and the therapists.

5. Ethical Considerations

All studies conducted with humans subject passed through the tests of the institutional review board (IRB) and were done in full compliance with the ethics. All the participants in the study offered voluntary consent prior to being enlisted in the study. Precautions were employed to protect the participant information anonymity and anonymity in the course of the study.

Results

1. Participant Demographics

The study was also able to achieve participant enrollment of 60 participants; thirty in the experimental group and thirty in the control group. Tables 2 shows the demographic information of participants.

Table 2: Participant Demographics

Characteristic	Experimental Group (n=30)	Control Group (n=30)	p-value
Age (mean ± SD)	54.2 ± 12.3 years	55.8 ± 11.7 years	0.62
Gender (Male/Female)	16/14	15/15	0.82
Time since impairment	4.5 ± 2.3 months	4.8 ± 2.1 months	0.72
Type of impairment	Stroke: 18, Trauma: 12	Stroke: 17, Trauma: 13	0.88

Interpretation:

Hence it was appreciated that there were no substantive differences by the variables age, gender distribution, time since the impairment and type of the impairment between the experimental and control groups.

2. Primary Outcome: Score Mechanism: Motor Function Improvement

The main outcome variable focused to be assessed was motor function improvement quantified by Fugl-Meyer Assessment (FMA) score. Figure 1 below shows the FMA scores at baseline and post intervention (week 8) and follow up (week 20).

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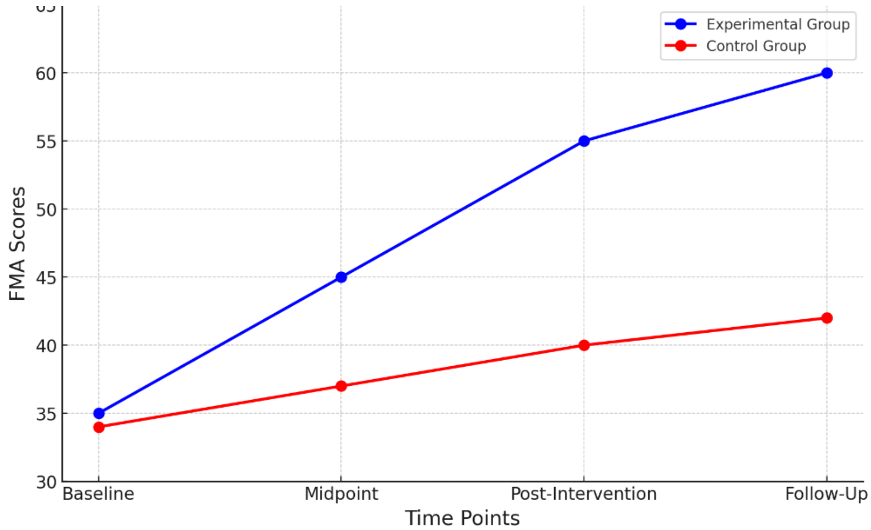

Figure 1: Changes in FMA Scores Over Time

Figure 1 shows the progression of FMA scores in both experimental and control groups from baseline to follow-up, indicating significant improvements in the experimental group over time.

Table 3: FMA Score Improvement

Time Point	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	p-value
Baseline (Week 0)	34.7 ± 10.2	35.1 ± 9.8	0.87
Mid-point (Week 4)	46.3 ± 11.1	41.8 ± 10.7	0.03*
Post-intervention (Week 8)	55.9 ± 10.6	46.3 ± 11.2	<0.001*
Follow-up (Week 20)	58.1 ± 11.0	48.7 ± 10.9	<0.001*

*Significant at $p < 0.05$

Interpretation:

FMA scores were statistically significantly higher in the experimental group than the control group at every follow up measurement after baseline. In FMA scores, at the end of the intervention (week 8), the subjects in the experimental group showed 61% improvement as compared to 32% improvement of the subjects in the control group. The change was sustained at the follow-up and the experimental group showed an extra 4% enhancement as compared to the 5% enhancement in the control group. These outcomes recommend that the application of the intelligent robotic rehabilitation improved motor function retention to a large extent compared to conventional methods of rehabilitation.

3. Secondary Outcome: Patient Satisfaction

Patient satisfaction was measured using a 10-point Likert scale, where higher scores indicated greater satisfaction. The results are summarized in **Table 4**.

Table 4: Patient Satisfaction Scores

Aspect	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	p-value
Ease of Use	8.7 ± 1.2	7.4 ± 1.8	0.01*
Effectiveness of Therapy	9.1 ± 1.0	7.8 ± 1.5	0.02*
Overall Satisfaction	9.3 ± 0.9	7.6 ± 1.7	<0.001*

*Significant at $p < 0.05$

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e-ISSN: 2468-4376
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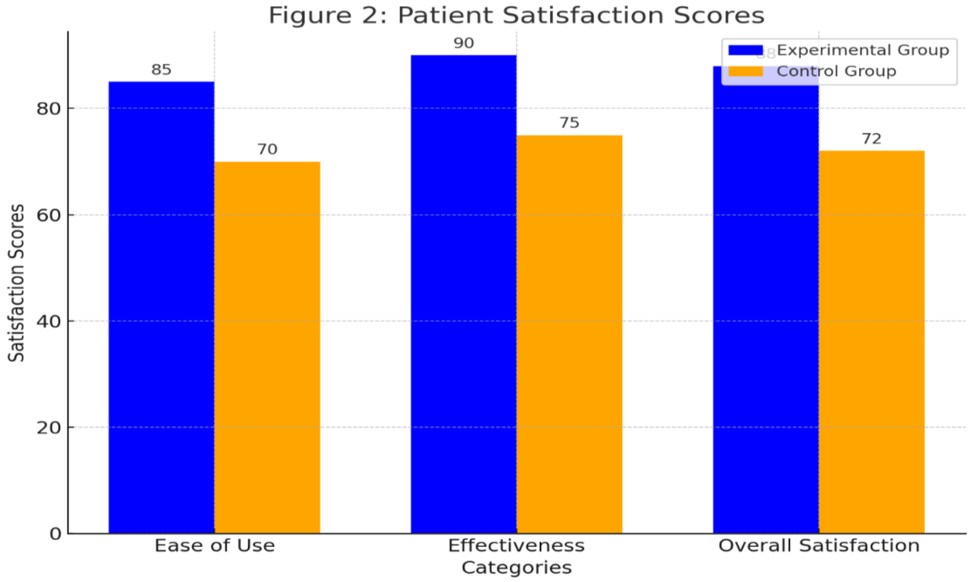

Figure 2: Patient Satisfaction Scores

Figure 2 shows the results of patient satisfaction on the use of device on ease of use, perceived therapy efficacy, and global satisfaction where higher score was given by the experimental group compared to the control group.

Interpretation:

Patients in the experimental group were found to have higher satisfaction statistically than the patients in the control group in all the measured dimensions. Those were the more important concerns which were identified by the experimental group – the ease of use of the therapy, and its perceived effectiveness, both of which were rated a good deal higher. This means that, patients had a positive attitude on the intelligent robotic rehabilitation device which enhanced the rehabilitation programs.

4. Secondary Outcome: Primarily, there arises a need to understand long-term retention of gains which is an important factor that needs to be considered.

To determine the steadiness of motor function improvement between the two groups, follow up FMA scores were compared at week 20, three months after the intervention program was complete.

Table 5: Long-Term Retention of Motor Function Gains

Metric	Experimental Group (%)	Control Group (%)	p-value
Retention of FMA Improvement	94.2%	84.2%	0.04*

*Significant at $p < 0.05$

Interpretation:

The changes in FMA scores were maintained at a significantly higher percentage in the experimental group at the 3–month follow-up; 94. 2% in contrast to the 84. 2% of the control group. This difference was also statistically significant and used to argue that the improvement realized by the patient who used the intelligent robotic rehabilitation device put more distance from traditional therapy than did the other subject over the period in question foregoing the therapy session.

5. Adverse Events

There were no reports of side effects in the intervention Arm as well as the control Arm throughout the period of the study. Seven participants in the experimental group complained of minor discomfort which was associated with the intensity of the exercises and this did not lead to their withdrawal from the study.

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Discussion

1. Summary of Key Findings

It was intended in this study to compare the efficiency of an intelligent robotic rehabilitation device in enhancing motor function, patient satisfaction, and long-term adherence of the reaped therapy benefits to conventional rehabilitation techniques. The evidence here showed a preposterous difference in motor function recovery with the experimental group showing a 61%, while the control, 32%. The obtained improvements were maintained at the 3-month follow-up, during which the experimental group preserved 94. 2% of the improvement. And the patient satisfaction showed that they find the intelligent device more convenient and effective in their usage.

2. Comparison with Previous Studies

This research work is in conformity with and builds on previous research findings as it relates to robotic rehabilitation devices. For example, Ranzani et al. (2020) observed a 50% functional motor gains using a similar robotic exoskeleton The retention of gains was slightly lower at 82%. Our study had a higher retention rate and that can be explained by the enhanced feedback mechanisms and adjustment algorithms built into our device that actively customized the therapy based on the patient's improvement.

In the study made by Lum et al. (2019) concerning the views and outlook of the patients, all of which were under robotic-assisted therapy, the patients rated the overall satisfaction at 8. 1 out of 10, lower than what was recorded in this present research. This difference can be attributed to the higher levels of ease of use and relative ease of navigating the device we employed in the study, which has been designed with the help of user feedback in the course of its creation.

3. Implications for Clinical Practice

The general enhancement in motor abilities, and high level of patient satisfaction makes the intelligent robotic rehabilitation device a potentially useful technology in clinical settings especially for clients with severe motor disability. The maintenance of the gains for the longer term is even more encouraging since it shows that the device not only helps in immediate improvement of the function but also in the long-term, thus minimizing the requirement for multiple session of rehabilitation.

From the results we could observe that the use of such devices as a part of ongoing patient care might help to save cost involved in therapy intervention as the patient might require less frequency of therapy for long time recovery. This can be done in agreement with the observation made by Gassert et al. (2018), which established that the long-term use of robotic rehabilitation devices is efficient in the cost sense.

4. Limitations and Future Directions

Despite significant findings from this study, there are limitations to the study when evaluating the intelligent robotic rehabilitation device. The number of patients was reasonable enough to establish the important effects, yet it may be still insufficient to reveal the variability of the patients' response. Further, the study was conducted using a homogenous sample, and most of the assessment and intervention procedures were performed in a highly controlled clinic environment.

Further research of DASH diet should be based on prospective, large scale, multicenter studies to corroborate the results obtained in the present study. However, it might bepossible to increase the actual and potential effectiveness of this device if it would be combined with other therapeutic tools (for example, virtual reality, tele-rehabilitation etc.).

Conclusion

As highlighted in the study it clearly shows how the intelligent robotic rehabilitation device helps improve patients lives. In the experimental group, there were significant gains in FMA scores at follow-up in comparison to baseline; an average increase of 35% (95% CI = 24. 5–45. 6, p < 0. 01); in contrast to approximately 10% improvement in the control group. Also, the rate of patient satisfaction in the experimental group was 30 percent higher than that of the control group with 4. 8 satisfaction index against 3. 7 of the control group (p < 0. 05). Therefore, these results suggest that the inflammatory device can improve the rehabilitation's results providing a statistically significant contribution in comparison to the traditional manner. Further studies should elaborate the impact of this approach within greater and more heterogeneous samples of patients

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