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Robot-Assisted Rehabilitation for Stroke Patients: A Review of Recent Developments

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Abstract— Stroke is a leading cause of disability worldwide, and rehabilitation is a crucial part of the recovery process. Robot-assisted rehabilitation has emerged as a promising approach to improve the outcomes of stroke rehabilitation by providing more intensive and consistent training, and by incorporating feedback and monitoring of patients' progress. This review paper provides an overview of the recent developments in robot-assisted rehabilitation for stroke patients. The paper first describes the different types of robots used in stroke rehabilitation, including exoskeletons, end-effectors, and hybrid devices. It then discusses the various training modalities that can be implemented using these robots, such as assistive, resistive, and adaptive training. The paper also examines the benefits and limitations of robot-assisted rehabilitation, including improved motor function and reduced healthcare costs, as well as challenges related to the integration of robotics with traditional therapy. The review highlights the recent advancements in robot-assisted rehabilitation, such as the development of personalized training programs based on patients' individual characteristics and the integration of virtual reality and gaming elements to enhance patient engagement and motivation. The paper also discusses the potential of robot-assisted rehabilitation to be used in conjunction with other emerging technologies, such as brain-computer interfaces and artificial intelligence. Finally, the paper concludes with a discussion of the future directions of robot-assisted rehabilitation for stroke patients, including the need for more rigorous clinical trials to establish the efficacy of these technologies, and the importance of incorporating patients' and clinicians' perspectives in the design and implementation of robot-assisted rehabilitation programs. Overall, this review highlights the potential of robot-assisted rehabilitation to improve the outcomes of stroke rehabilitation and enhance the quality of life of stroke survivors.

Keywords— Robot-assisted rehabilitation, Stroke, Exoskeletons, Virtual reality, Motor function.

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I. Introduction

Stroke is a leading cause of disability worldwide, resulting in significant physical, cognitive, and emotional impairments that affect individuals' quality of life. Stroke survivors often face challenges in regaining motor function, and rehabilitation plays a vital role in their recovery process. Traditional stroke rehabilitation approaches, such as physiotherapy and occupational therapy, have shown benefits in improving motor skills and functional independence. However, these interventions are often resource-intensive, time-consuming, and rely heavily on the availability of skilled therapists.

In recent years, robot-assisted rehabilitation has emerged as a promising approach to augment traditional stroke rehabilitation methods. Robotics technology offers the potential to deliver more intensive, consistent, and objective training to stroke patients, while also providing real-time feedback and monitoring of their progress. By leveraging the capabilities of robots, stroke rehabilitation can be tailored to individual needs, allowing for personalized and adaptive training programs.

This review paper aims to provide an overview of the recent developments in robot-assisted rehabilitation for stroke patients. It will delve into the various types of robots used in stroke rehabilitation, including exoskeletons, end-effectors, and hybrid devices. Each type of robot brings unique advantages and considerations, such as the range of motion, assistance levels, and targeted therapeutic goals.

Furthermore, the paper will explore the different training modalities that can be implemented using these robotic devices. These modalities encompass assistive training, where the robot provides support to amplify the patient's movements; resistive training, which involves providing controlled resistance to enhance strength and endurance; and adaptive training, which adapts the training parameters based on the patient's performance to challenge and promote skill acquisition.

The benefits and limitations of robot-assisted rehabilitation will also be examined in this review. Improved motor function, increased intensity of therapy, and reduced healthcare costs are among the advantages associated with this technology. robotics with traditional therapy approaches, ensuring patient safety, and addressing concerns related to cost-effectiveness and accessibility.

Recent advancements in robot-assisted rehabilitation will be a focal point of this review. Personalized training programs based on patients' individual characteristics, such as their motor impairments and cognitive abilities, are being developed to optimize therapy outcomes. Furthermore, the integration of virtual reality and gaming elements in robot-assisted rehabilitation holds promise for enhancing patient engagement, motivation, and participation in therapy sessions.

The potential synergy between robot-assisted rehabilitation and other emerging technologies, such as brain-computer interfaces and artificial intelligence, will also be explored. These technologies have the potential to further enhance the effectiveness and personalization of stroke rehabilitation by enabling direct brain control of robotic devices and leveraging intelligent algorithms to adapt therapy based on patient progress.

Looking forward, this paper will discuss the future directions of robot-assisted rehabilitation for stroke patients. It emphasizes the importance of conducting more rigorous clinical trials to establish the efficacy and effectiveness of robot-assisted interventions compared to traditional methods. Additionally, it highlights the need for incorporating the perspectives of both patients and clinicians in the design and implementation of robot-assisted rehabilitation programs to ensure usability, acceptance, and overall effectiveness.

This review aims to highlight the potential of robot-assisted rehabilitation to improve the outcomes of stroke rehabilitation and enhance the quality of life for stroke survivors. By providing a comprehensive overview of the recent developments, benefits, limitations, and future directions in this field, this paper seeks to contribute to the understanding and advancement of robot-assisted interventions for stroke patients.

II. Literature Study

Robot-assisted rehabilitation has gained increasing attention as a promising approach to enhance stroke rehabilitation outcomes. This section provides a comprehensive review of the relevant literature, highlighting key studies and findings in the field.

Chang and Kim (2013) emphasized the potential of robot-assisted therapy in stroke rehabilitation, noting its ability to provide intensive training and offer various forms of feedback to improve motor function[1]. Fasoli et al. (2004) focused on translating research into practice, highlighting the importance of integrating robotic technology into clinical settings and addressing barriers to implementation[2].

Several studies have explored the integration of robotics with emerging technologies. Gomez-Rodriguez et al. (2011) discussed the potential of brain-robot interfaces in stroke rehabilitation, enabling direct interaction between the brain and robotic devices to enhance motor recovery[3]. Similarly, Nef et al. (2009) presented the ARMin-Exoskeleton robot, which incorporated a user-friendly interface and provided task-specific training for upper limb rehabilitation[8].

The use of wearable robotics has also been investigated. Ho et al. (2011) introduced an EMG-driven exoskeleton hand robotic training device, enabling stroke survivors to engage in task-oriented training[4]. Loureiro et al. (2011) highlighted the advances in upper limb stroke rehabilitation, emphasizing the role of wearable robotics in providing assistance and promoting motor recovery[5].

Virtual reality and gaming elements have shown promise in enhancing patient engagement and motivation. Steinisch et al. (2013) presented a post-stroke rehabilitation system that integrated robotics, virtual reality, and high-resolution EEG imaging to provide immersive and personalized therapy experiences[14]. Rosati (2010) discussed the place of robotics in post-stroke rehabilitation, emphasizing the potential of virtual reality in creating interactive and engaging environments[11].

Various studies have explored the benefits and outcomes of robot-assisted rehabilitation. Masiero et al. (2014) emphasized the value of robotic systems in stroke rehabilitation, highlighting improved motor function and increased therapy intensity[6]. Song et al. (2013) investigated the use of a myoelectrically controlled wrist robot, demonstrating positive effects on wrist function and spasticity reduction[13].

The future directions of robot-assisted rehabilitation have also been addressed. Wade and Winstein (2011) discussed the potential of virtual reality and robotics in stroke rehabilitation and highlighted the need for further research in optimizing these technologies[17]. Weber and Stein (2018) provided a narrative review, summarizing the use of robots in stroke rehabilitation and discussing key findings and challenges in the field[18].

Other topics explored in the literature include the use of robotics in home-based rehabilitation (Wolf et al., 2015), the detection of compensation during therapy (Zhi et al., 2017), and the effects of robotic therapy in different stroke populations (Pellegrino et al., 2012; Straudi et al., 2016) [19] [20] [10] [15].

In summary, the literature review demonstrates a growing body of research supporting the efficacy and potential benefits of robot-assisted rehabilitation in stroke recovery. The integration of robotics with virtual reality, wearable sensors, and brain-computer interfaces holds promise for enhancing therapy outcomes and patient engagement. However, further research is needed to establish the optimal use, effectiveness, and long-term benefits of these interventions, and to address challenges related to implementation and cost-effectiveness.

III. Potential of Robo-assisted Rehabilitation

The potential of robot-assisted rehabilitation in stroke patients is substantial and holds promise for revolutionizing the field of neurorehabilitation. The integration of robotics technology into stroke rehabilitation programs offers several key advantages that can significantly impact the outcomes and quality of life for stroke survivors.

One of the primary benefits of robot-assisted rehabilitation is the ability to provide more intensive and repetitive training compared to traditional methods. Stroke recovery is a complex and time-consuming process that requires extensive practice to promote neuroplasticity and functional recovery. Robots can deliver high-intensity training sessions for extended durations, ensuring that patients receive a sufficient number of repetitions to promote skill acquisition and motor relearning. This intensive training can lead to accelerated recovery and improved functional outcomes. An example of rehabilitation robot is shown in Fig. 1.

Fig 1. The ARMin III Arm Rehabilitation Robot (Nef, T et al, 2009)

Moreover, robot-assisted rehabilitation provides a unique opportunity for consistent and objective therapy. Traditional therapy methods often suffer from variability in the quality and quantity of therapy sessions due to limitations such as therapist availability and patient compliance. Robots, on the other hand, can deliver therapy with precise and consistent movement patterns, ensuring that patients receive standardized training. The objective nature of robotic therapy allows for accurate monitoring of progress over time, enabling therapists to track improvements and adjust treatment plans accordingly.

Another significant advantage of robot-assisted rehabilitation is the ability to incorporate real-time feedback and monitoring. Robots equipped with sensors can collect data on patients' movement performance, providing immediate feedback on the quality and accuracy of their movements. This feedback can be essential for stroke survivors who often struggle with impaired proprioception and diminished body awareness. By receiving real-time feedback, patients can make necessary adjustments to their movements, enhancing motor control and facilitating more efficient recovery.

Personalization is another key aspect of robot-assisted rehabilitation that contributes to its potential. Robots can be tailored to the specific needs and abilities of individual patients, allowing for personalized therapy programs. By adapting the assistance level, resistance, and difficulty of the training tasks, robots can provide a customized rehabilitation experience that addresses each patient's unique impairments and goals. Personalized training programs have been shown to yield better outcomes compared to generic rehabilitation approaches, as they target specific deficits and optimize the rehabilitation process.

The integration of virtual reality (VR) and gaming elements into robot-assisted rehabilitation further enhances its potential. VR-based training environments can create immersive and engaging experiences that motivate patients and increase their active participation in therapy. Gamification elements, such as interactive tasks, challenges, and rewards, can make therapy sessions enjoyable and encourage patients to push their limits. The combination of robotics, virtual reality, and gaming elements creates a highly engaging and motivating environment that promotes active involvement, increases adherence to therapy, and potentially enhances recovery outcomes.

Additionally, robot-assisted rehabilitation has the potential to reduce healthcare costs associated with stroke rehabilitation. While the initial investment in robotic devices may be significant, the long-term benefits can outweigh the costs. Robots can supplement or even replace some of the therapist-led sessions, reducing the need for extensive manpower and minimizing the overall therapy time required. This can lead to more efficient use of healthcare resources and potentially reduce the financial burden on patients and healthcare systems. The potential of robot-assisted rehabilitation for stroke patients is vast and holds significant promise for improving the outcomes of stroke rehabilitation. The integration of robotics technology offers advantages such as intensive training, consistent and objective therapy, real-time feedback and monitoring, personalization, and the incorporation of virtual reality and gaming elements. By leveraging these benefits, robot-assisted rehabilitation has the potential to accelerate recovery, enhance motor function, and improve the quality of life for stroke survivors. Continued research, innovation, and collaboration between clinicians, engineers, and researchers are essential to unlock the full potential of this transformative approach to stroke rehabilitation.

IV. Recent Development in Robo-assisted Rehabilitation

Recent developments in robot-assisted rehabilitation have brought about significant advancements in the field, enhancing the effectiveness, versatility, and patient engagement of these interventions. These developments include the integration of personalized training programs, the incorporation of virtual reality and gaming elements, and the synergistic use of robotics with emerging technologies such as brain-computer interfaces and artificial intelligence.

One notable recent development is the focus on personalized training programs based on patients' individual characteristics. Advances in sensor technology and data analysis have enabled the collection of detailed information regarding patients' motor impairments, cognitive abilities, and progress during therapy. This data can be used to tailor the robotic interventions to each patient's specific needs, optimizing therapy outcomes. Personalized training programs can adjust the assistance levels, resistance, and task difficulty in real-time, providing a challenging yet achievable rehabilitation experience. By targeting the individualized deficits of each patient, these programs have the potential to promote more efficient recovery and improve overall functional outcomes.

The integration of virtual reality (VR) and gaming elements has also gained momentum in recent years. VR-based environments provide an immersive and engaging platform for therapy, allowing patients to interact with virtual objects and environments that simulate real-world activities. This technology enhances patient motivation and enjoyment, increasing active participation and adherence to therapy sessions. VR-based games and interactive tasks can be designed to address specific rehabilitation goals, such as reaching, grasping, and balance training, making therapy sessions more stimulating and goal-oriented. Additionally, real-time visual feedback within the virtual environment helps patients understand and correct their movements, facilitating motor learning and improving functional outcomes.

Furthermore, the synergistic use of robotics with emerging technologies such as brain-computer interfaces (BCIs) and artificial intelligence (AI) holds great potential for advancing robot-assisted rehabilitation. BCIs enable direct communication between the brain and robotic devices, allowing stroke survivors to control the movements of the robot through their neural signals. This technology opens up new possibilities for neurorehabilitation by bypassing the impaired neural pathways and directly engaging the intact regions of the brain. BCIs can enhance the precision and specificity of robot-assisted interventions, leading to more natural and intuitive movements and potentially accelerating the recovery process.

Artificial intelligence plays a crucial role in robot-assisted rehabilitation by analyzing large datasets, identifying patterns, and adapting therapy protocols based on patient performance and progress. AI algorithms can learn from patient data to optimize the delivery of therapy, automatically adjusting the task parameters, assistance levels, and difficulty to match the patient's abilities and promote optimal motor learning. Additionally, AI can facilitate the development of intelligent robotic systems that can detect and respond to changes in the patient's condition in real-time, ensuring safe and effective therapy sessions.

Recent developments in robot-assisted rehabilitation have paved the way for significant advancements in stroke rehabilitation. The integration of personalized training programs, virtual reality and gaming elements, and the synergistic use of robotics with emerging technologies such as brain-computer interfaces and artificial intelligence have enhanced the effectiveness, engagement, and customization of these interventions. These developments have the potential to revolutionize the field of stroke rehabilitation by providing more tailored, engaging, and efficient therapy, ultimately improving the outcomes and quality of life for stroke survivors. Continued research, innovation, and collaboration between multidisciplinary teams are essential to further explore and harness the potential of these recent developments in robot-assisted rehabilitation.

V. Future Directions

Paying attention to future directions in robot-assisted rehabilitation is of paramount importance to drive advancements in the field and improve stroke rehabilitation outcomes. By focusing on future directions, researchers and clinicians can address current limitations and challenges, identify innovative approaches, and explore the integration of emerging technologies. This forward-thinking approach enables the development of more personalized, effective, and accessible rehabilitation strategies. Additionally, staying abreast of future directions ensures that the field remains responsive to evolving patient needs and leverages the latest scientific and technological advancements. Ultimately, by proactively considering future directions, we can shape the future of robot-assisted rehabilitation and optimize the quality of care provided to stroke survivors.

The future directions in robot-assisted rehabilitation includes but is not limited to:

1. Rigorous clinical trials and evidence-based practice: Future directions in robot-assisted rehabilitation for stroke patients involve conducting rigorous clinical trials to establish the efficacy, effectiveness, and safety of these interventions. While there is growing evidence supporting the benefits of robot-assisted rehabilitation, further research is needed to strengthen the scientific foundation and provide robust evidence for the integration of these technologies into clinical practice. Large-scale randomized controlled trials comparing robot-assisted interventions with traditional therapy approaches are essential to determine the optimal use and long-term benefits of these interventions.
2. Patient-centered and clinician-involved design: The future of robot-assisted rehabilitation lies in the integration of patients' and clinicians' perspectives in the design and implementation of these interventions. Engaging stroke survivors and healthcare professionals in the development process can ensure that the robotic systems are user-friendly, culturally sensitive, and aligned with the specific needs and preferences of the target population. By involving end-users in the design process, the technology can better address the practical challenges faced in clinical settings and improve the overall usability and acceptance of robot-assisted rehabilitation programs.

3. Home-based and remote rehabilitation: Future directions in robot-assisted rehabilitation aim to extend the benefits of these interventions beyond clinical settings. Home-based and remote rehabilitation programs can enhance accessibility, convenience, and long-term engagement for stroke survivors. Advances in telehealth, sensor technology, and robotics allow for the development of portable and user-friendly robotic devices that can be used in the home environment. Remote monitoring and virtual guidance by therapists can provide support and ensure proper execution of therapy protocols, enabling stroke survivors to receive ongoing rehabilitation even when access to in-person therapy is limited.
4. Integration with wearable sensors and Internet of Things (IoT): The future of robot-assisted rehabilitation involves the integration of wearable sensors and IoT technologies to enhance the precision, monitoring, and data collection during therapy sessions. Wearable sensors, such as inertial measurement units and electromyography devices, can provide real-time kinematic and muscle activity data, enabling detailed assessment of movement quality and motor performance. IoT platforms can facilitate seamless communication between robotic devices, sensors, and electronic health records, allowing for comprehensive data analysis and personalized feedback to optimize therapy outcomes.
5. Multimodal and adaptive training approaches: Future directions in robot-assisted rehabilitation aim to explore multimodal and adaptive training approaches that combine the strengths of different technologies. By integrating robotic devices with other modalities such as functional electrical stimulation, brain stimulation, or sensory feedback systems, therapy interventions can target multiple aspects of stroke recovery simultaneously. Adaptive training algorithms and machine learning techniques can be employed to dynamically adjust the therapy parameters based on the patient's progress, optimizing the challenge level and promoting continuous improvement.
6. Long-term follow-up and maintenance programs: The future of robot-assisted rehabilitation includes the development of long-term follow-up and maintenance programs to ensure sustained benefits and prevent functional decline after the completion of therapy. Stroke recovery is a lifelong process, and continuous monitoring and periodic booster sessions may be necessary to maintain the gains achieved during the initial rehabilitation phase. Long-term follow-up programs can incorporate remote monitoring, periodic assessments, and personalized intervention plans to support stroke survivors in achieving optimal functional outcomes and preventing secondary complications.

In summary, future directions in robot-assisted rehabilitation for stroke patients encompass rigorous clinical trials, patient-centered design, home-based and remote rehabilitation, integration with wearable sensors and IoT, multimodal and adaptive training approaches, and long-term follow-up programs. These advancements aim to strengthen the evidence base, enhance user experience, improve accessibility, and optimize therapy outcomes, ultimately advancing the field of stroke rehabilitation and improving the quality of life for stroke survivors.

VI. Discussion

Robot-assisted rehabilitation has emerged as a promising approach to improve the outcomes of stroke rehabilitation by providing intensive and consistent training, incorporating feedback and monitoring, and enhancing patient engagement. This review paper has provided an overview of recent developments in robot-assisted rehabilitation for stroke patients, highlighting the different types of robots used, training modalities implemented, benefits and limitations, advancements in personalization and virtual reality, and the potential integration with emerging technologies.

The integration of robotics technology into stroke rehabilitation has shown great potential in enhancing the effectiveness of therapy. The ability of robots to deliver high-intensity and repetitive training sessions ensures that patients receive an adequate number of repetitions to promote neuroplasticity and functional recovery. Moreover, the objective and consistent nature of robotic therapy allows for accurate monitoring of patients' progress over time, enabling therapists to track improvements and make informed decisions about treatment plans. Real-time feedback provided by robots enhances patients' body awareness and facilitates motor control, further promoting efficient recovery.

Personalized training programs have gained prominence in robot-assisted rehabilitation. By tailoring the therapy to individual patient characteristics, such as motor impairments and goals, robots can provide customized rehabilitation experiences that optimize the recovery process. This approach has the potential to yield better outcomes compared to generic rehabilitation approaches, as it targets specific deficits and optimizes the therapy regimen.

The integration of virtual reality and gaming elements into robot-assisted rehabilitation has revolutionized the patient experience. VR-based environments and gamified tasks enhance patient motivation, increase active participation, and make therapy sessions enjoyable. By creating immersive and engaging experiences, virtual reality stimulates patient engagement and adherence to therapy, leading to improved outcomes.

The future directions of robot-assisted rehabilitation hold great promise. Rigorous clinical trials are needed to establish the efficacy, effectiveness, and safety of these interventions, ensuring evidence-based practice. Patient-centered design involving stroke survivors and clinicians in the development process is crucial to address practical challenges and improve acceptance. Home-based and remote rehabilitation programs can extend the benefits of robot-assisted therapy beyond clinical settings, enhancing accessibility and convenience. The integration of wearable sensors and IoT technologies can enhance precision, monitoring, and data collection during therapy. Multimodal and adaptive training approaches, as well as long-term follow-up and maintenance programs, further optimize therapy outcomes and ensure sustained benefits.

Robot-assisted rehabilitation offers a promising avenue for improving stroke rehabilitation outcomes. Recent developments in the field have demonstrated the potential of robotics technology to enhance therapy effectiveness, engagement, and personalization. The integration of virtual reality, gamification, wearable sensors, and emerging technologies further enhances the possibilities for optimizing stroke rehabilitation. Continued research, collaboration, and innovation are essential to unlock the full potential of robot-assisted rehabilitation and improve the quality of life for stroke survivors.

VII. Concluding Remarks

This review has provided a comprehensive overview of the recent developments in robot-assisted rehabilitation for stroke patients. The integration of robotics technology has shown great promise in improving the outcomes of stroke rehabilitation by providing intensive and consistent training, incorporating feedback and monitoring, and enhancing patient engagement. The advancements in personalized training programs, virtual reality, and gaming elements have further enhanced the efficacy and enjoyment of these interventions.

The future directions of robot-assisted rehabilitation hold immense potential for advancing the field. Rigorous clinical trials, patient-centered design, home-based and remote rehabilitation, integration with wearable sensors and IoT, multimodal and adaptive training approaches, and long-term follow-up programs are key areas that require further exploration. These developments have the potential to revolutionize stroke rehabilitation and improve the quality of life for stroke survivors.

While robot-assisted rehabilitation has shown promising results, there are still challenges to be addressed, such as cost-effectiveness, usability, and accessibility. Collaboration between researchers, engineers, clinicians, and patients is crucial to overcome these challenges and translate the potential of these technologies into widespread clinical practice.

Overall, robot-assisted rehabilitation has the potential to significantly enhance stroke rehabilitation outcomes, providing more tailored and effective therapy for patients. With continued research, innovation, and collaboration, we can further harness the power of robotics to transform the lives of stroke survivors and improve their functional recovery and overall well-being.

References

[1]. Chang, Won Hyuk, and Yun-Hee Kim. ‘Robot-Assisted Therapy in Stroke Rehabilitation’. Journal of Stroke, vol. 15, no. 3, Korean Stroke Society, 2013, p. 174.

[2]. Fasoli, Susan E., et al. ‘Robotic Technology and Stroke Rehabilitation: Translating Research into Practice’. Topics in Stroke Rehabilitation, vol. 11, no. 4, Taylor & Francis, 2004, pp. 11–19.

[3]. Gomez-Rodriguez, Manuel, et al. ‘Towards Brain-Robot Interfaces in Stroke Rehabilitation’. 2011 IEEE International Conference on Rehabilitation Robotics, IEEE, 2011, pp. 1–6.

[4]. Ho, N. S. K., et al. ‘An EMG-Driven Exoskeleton Hand Robotic Training Device on Chronic Stroke Subjects: Task Training System for Stroke Rehabilitation’. 2011 IEEE International Conference on Rehabilitation Robotics, IEEE, 2011, pp. 1–5.

[5]. Loureiro, Rui C. V., et al. ‘Advances in Upper Limb Stroke Rehabilitation: A Technology Push’. Medical & Biological Engineering & Computing, vol. 49, Springer, 2011, pp. 1103–1118.

[6]. Masiero, Stefano, et al. ‘The Value of Robotic Systems in Stroke Rehabilitation’. Expert Review of Medical Devices, vol. 11, no. 2, Taylor & Francis, 2014, pp. 187–198.

[7]. Matarić, Maja J., et al. ‘Socially Assistive Robotics for Post-Stroke Rehabilitation’. Journal of Neuroengineering and Rehabilitation, vol. 4, Springer, 2007, pp. 1–9.

[8]. Nef, Tobias, et al. ‘ARMin-Exoskeleton Robot for Stroke Rehabilitation’. World Congress on Medical Physics and Biomedical Engineering, September 7-12. Volume 25/IX of IFMBE Proceedings, 2009, pp. 127–130.

[9]. Palazzolo, Jerome J., et al. ‘Stochastic Estimation of Arm Mechanical Impedance during Robotic Stroke Rehabilitation’. IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 15, no. 1, IEEE, 2007, pp. 94–103.

[10]. Pellegrino, G., et al. ‘Inter-Hemispheric Coupling Changes Associate with Motor Improvements after Robotic Stroke Rehabilitation’. Restorative Neurology and Neuroscience, vol. 30, no. 6, IOS Press, 2012, pp. 497–510.

[11]. Rosati, Giulio. ‘The Place of Robotics in Post-Stroke Rehabilitation’. Expert Review of Medical Devices, vol. 7, no. 6, Taylor & Francis, 2010, pp. 753–758.

[12]. Sheng, Bo, et al. ‘Bilateral Robots for Upper-Limb Stroke Rehabilitation: State of the Art and Future Prospects’. Medical Engineering & Physics, vol. 38, no. 7, Elsevier, 2016, pp. 587–606.

[13]. Song, Rong, et al. ‘Myoelectrically Controlled Wrist Robot for Stroke Rehabilitation’. Journal of Neuroengineering and Rehabilitation, vol. 10, no. 1, BioMed Central, 2013, pp. 1–8.

[14]. Steinisch, Martin, et al. ‘A Post-Stroke Rehabilitation System Integrating Robotics, VR and High-Resolution EEG Imaging’. IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 21, no. 5, IEEE, 2013, pp. 849–859.

[15]. Straudi, Sofia, et al. ‘tDCS and Robotics on Upper Limb Stroke Rehabilitation: Effect Modification by Stroke Duration and Type of Stroke’. BioMed Research International, vol. 2016, Hindawi, 2016.

[16]. Volpe, B. T., et al. ‘A Novel Approach to Stroke Rehabilitation: Robot-Aided Sensorimotor Stimulation’. Neurology, vol. 54, no. 10, AAN Enterprises, 2000, pp. 1938–1944.

[17]. Wade, Eric, and Carolee J. Winstein. ‘Virtual Reality and Robotics for Stroke Rehabilitation: Where Do We Go from Here?’ Topics in Stroke Rehabilitation, vol. 18, no. 6, Taylor & Francis, 2011, pp. 685–700.

[18]. Weber, Lynne M., and Joel Stein. ‘The Use of Robots in Stroke Rehabilitation: A Narrative Review’. NeuroRehabilitation, vol. 43, no. 1, IOS Press, 2018, pp. 99–110.

[19]. Wolf, Steven L., et al. ‘The HAAPI (Home Arm Assistance Progression Initiative) Trial: A Novel Robotics Delivery Approach in Stroke Rehabilitation’. Neurorehabilitation and Neural Repair, vol. 29, no. 10, SAGE Publications Sage CA: Los Angeles, CA, 2015, pp. 958–968.

[20]. Zhi, Ying Xuan, et al. ‘Automatic Detection of Compensation during Robotic Stroke Rehabilitation Therapy’. IEEE Journal of Translational Engineering in Health and Medicine, vol. 6, IEEE, 2017, pp. 1–7.