

Platform-Based Robot-Assisted Rehabilitation

Subjects: Rehabilitation

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The use of robotic-assisted rehabilitation has increased significantly. Compared with traditional care, robotic rehabilitation has several potential advantages. Platform-based robotic rehabilitation can help patients recover from musculoskeletal and neurological conditions. Evidence on how platform-based robotic technologies can positively impact on disability recovery is still lacking, and it is unclear which intervention is most effective in individual cases. The Virtual Reality (VR)-based Rutgers Ankle and the Hunova were found to be the effective robots for the rehabilitation of patients with neurological conditions (stroke, spinal cord injury, Parkinson's disease) and various musculoskeletal ankle injuries.

Keywords: robot-assisted training ; platform-based robotic rehabilitation ; Parkinson's disease ; stroke ; spinal cord injuries ; neuro-rehabilitation ; orthopedic-rehabilitation

1. Introduction

In the last several years, the use of robotic-assisted rehabilitation has increased significantly ^{[1][2]}. Compared with traditional care, robotic rehabilitation can be better performed at high intensity and frequency, and can continuously monitor exercise performance so that the level of treatment can be better adapted to the patient's needs ^[3], and can generate more appropriate movements and forces during training ^{[4][5]}.

Two major types of robotic rehabilitation devices are available. The first one consists of wearable devices: robotic orthoses ^[6] and exoskeletons ^[7] for correcting the gait pattern of patients and improving ankle performance during walking. The second one includes platform-based devices that are designed solely to improve ankle performance ^{[8][9]}. These technologies have a fixed platform and a movable footplate that can be used with a single degree of freedom (DOF) ^[10] or multiple degrees of freedom (DOFs) ^{[11][12]}. Platform-based robotic rehabilitation allows for complex and specialized spatial movements ^{[11][12][13][14]}. Their architectures provide the device with high stiffness, balanced force distribution, and improved adaptability to the mechanical properties of human ankle joints ^[13]. The utilization of platform-based robotic rehabilitation can help the patients recovering from neurological conditions (e.g., stroke, brain injury, spinal cord injury, and cerebral palsy) and musculoskeletal disorders (e.g., post-traumatic lower-limb disorders).

2. Effectiveness of Platform-Based Robot-Assisted Rehabilitation for Musculoskeletal or Neurologic Injuries

It is showed that patients with neurological impairments and musculoskeletal injuries can be effectively treated with platform-based robotic rehabilitation devices after their health status is stabilized. With the higher repetitions that robotic devices provide, patients can exercise more, which stimulates neural plasticity in neurological patients in the early stages of their recovery. Once patients can walk better, they can transition to conventional walking to further practice walking on different terrain, improve balance, and correct abnormal gait patterns.

Therefore, platform-based robotic training should be routinely adopted in rehab clinics next to traditional physical therapy. In fact, physiotherapists can use robotic equipment as a multiplier to train more patients. Instead of traditional one-to-one practice, therapists can use robotic devices to treat more patients at the same time. This frees up valuable time for therapists to either train severe patients individually or practice more function-based tasks that require the integration of multiple motor skills. By spending their time on this higher value training activities and letting the robotic devices take over the "heavy" routine tasks, therapists can provide an appropriate level of personalized treatment to their patients and increase their efficiency.

Herein found that the Virtual Reality(VR)-based Rutgers ankle and Hunova seemed to be the most effective robots for rehabilitation. Ankle rehabilitation using a VR-based Rutgers ankle robot has been shown to be effective in rehabilitating patients after stroke and various musculoskeletal ankle injuries ^{[15][16][17][18][19][20]}. It is also found that rehabilitation treatment with Hunova is an innovative therapeutic option that can be combined with traditional rehabilitation in patients

with Parkinson's disease [21][22][23], a promising tool for the rehabilitation of stroke patients [24]. For spinal cord injuries (SCI), it can be a useful rehabilitation tool for assessment and training [25][26][27]. In addition, rehabilitation with the Hunova allows measurement of important parameters of static and dynamic stability and can focus on a complex sequence of exercises to restore trunk control and reactive balance after traumatic injury. In the elderly population, the Hunova has the potential to effectively predict fall risk [28]. In patients after traumatic injuries, the Hunova can effectively restore trunk control and reactive balance [25][26][27].

Researchers have studied platform-based robotic rehabilitation in different phases (acute phase, subacute phase, and chronic phase) and at different time points in patients after injuries. Saglia et al. [11], have summarized the rehabilitation protocol for ankle injuries. In the early phase of ankle therapy, the patient can hardly move his foot. Therefore, passive exercises are usually required, during which the movement parameters such as speed, amplitude, and number of repetitions can be determined by the physical therapist. Active exercises can then help the patient regain ROM to move the ankle fully again. Strength training includes both isometric and isotonic exercises. In the final phase of rehabilitation, the patient must perform proprioceptive training (e.g., balance exercises) [11]. Therefore, it is believed that an early-stage intervention leads to a faster recovery of the patient than a late-stage intervention. The reason for this is that patients need to do passive exercises in the initial phase. After that, patients need to do active exercises to regain ROM and proprioceptive training (like balance exercises). In contrast, late-stage patients need more exercise sessions to rehabilitate and recover. However, it would be interesting to investigate this in the future through further studies with larger samples.

Bessler et al. reported about 17 adverse events, including tissue-related, musculoskeletal, and physiological adverse events (adverse blood pressure changes) with the use of stationary gait robots (exoskeletons and end-effector) [29][30]. However, for the platform-based robotic devices, herein found insufficient literature on adverse events related to long-term use and training. It is not sure and cannot predict what type of adverse events will occur in patients trained with platform-based robots. Future research may provide clues about the adverse effects. This inability to predict adverse events exists because research in the field of robotic rehabilitation is still in its beginning stage.

Robotic rehabilitation was positively evaluated by physiotherapists and occupational therapists. They reported that patients like to use robotic devices for rehabilitation and that they increase accessibility, autonomy, and comfort, and reduce costs [31][32][33][34][35][36]. Therefore, it is believed that physiotherapists will have no problems in using the platform-based robotic devices. However, training is required and the amount of training that physiotherapists need depends on how quickly they grasp and understand the functions of the robotic devices. Indeed, the platform-based robots are user-friendly and widely accepted by physiotherapists [12].

3. Conclusions

It is showed that rehabilitation by using platform-based robots had some encouraging results. The use of robotic rehabilitation allows efficient planning of the rehabilitation process in terms of the duration of sessions, required tools, and availability of a therapist. Therefore, compared to traditional rehabilitation that require combined and intensive efforts of therapists and patients, robotic-assisted rehabilitation should reduce costs because of a shorter hospital stay and greater autonomy at discharge. This highlights the importance of novel rehabilitation techniques that allow therapists to deliver effective treatment interventions while reducing the burden on staff and resources, and related costs. Robotic technology has the potential to transform rehabilitation clinics from labor-intensive to technology-enabled workflows, providing a rich stream of data to help diagnose patients, adjust therapy, and maintain patient records (in a clinic and at home).

It is believed that further studies able to provide results with a higher level of evidence are needed to confirm the effectiveness of platform-based robotic rehabilitation devices. This should primarily include the execution of large sample-size RCTs. These studies should be based on rigorous comparison among the available devices (interventions) and usual care (that is, non-robotic conventional therapies (control)), and should necessarily adopt standardized outcomes to better compare the different models of platform-based rehabilitation robots and to effectively generalize the eventual findings. Therefore, new outcome research is also needed to define universally accepted evaluation criteria able to standardize the devices' outcomes evaluation. To this end, the group also thinks that wider outcomes should be evaluated, including assessment of comfort, safety, and training performance for the end user.

Despite most studies' claims that platform-based robots would increase rehabilitation intensity, they allow complex and specialized spatial movements, and the architectures give the robotic device high stiffness, balanced force distribution, and better adaptability to the mechanical properties of human ankles. This robotic technology can be effectively used by the physiotherapists in the rehabilitation units.

Moreover, in the era of big data and artificial intelligence (AI), computer models can be developed to understand recovery mechanisms, predict the use of different motor control strategies, and ultimately tailor treatment to the patient. It is a need to emphasize that platform-based robotic rehabilitation can only be effective if it would be considered an added value by the patient. Indeed, it is important to consider the perspective of the end user when developing a particular platform-based robotic device to support a specific dysfunction. Such a synergistic effort will certainly lead to effective treatment.

In addition, future research should also focus on the structured and complete recording and dissemination of adverse events related to platform-based robotic rehabilitation to increase knowledge about risks. With this information, appropriate risk mitigation strategies can and should be developed and implemented in platform-based robotic devices to enhance their safety.

Finally, among the platform-based robots studied, the Hunova robot by Movendo technology is commercialized and already available on the market (<https://www.movendo.technology/en/>) (accessed on 1 August 2021). Therefore, it is assumed that it has undergone several safety validations before its market launch. In some studies that investigated the Hunova robot, end users also gave positive feedback on training performance and reported that they felt comfortable using the robot for rehabilitation.

References

1. Loureiro, R.C.V.; Harwin, W.S.; Nagai, K. Advances in upper limb stroke rehabilitation: A technology push. *Med. Biol. Eng. Comput.* 2011, 49, 1103–1118.
2. Péter, O.; Fazekas, G.; Zsiga, K. Robot-mediated upper limb physiotherapy: Review and recommendations for future clinical trials. *Int. J. Rehabil. Res.* 2011, 34, 196–202.
3. Volpe, B.T.; Krebs, H.I.; Hogan, N. Robot-aided sensorimotor training in stroke rehabilitation. *Curr. Opin. Neurol.* 2001, 14, 745–752.
4. Bosecker, C.; Dipietro, L.; Volpe, B. Kinematic Robot-Based Evaluation Scales and Clinical Counterparts to Measure Upper Limb Motor Performance in Patients with Chronic Stroke. *Neurorehabil. Neural. Repair.* 2010, 24, 62–69.
5. Krebs, H.; Hogan, N.; Aisen, M. Robot-Aided Neurorehabilitation. *IEEE Trans. Rehabil. Eng.* 1998, 6, 75–87.
6. Park, Y.L.; Chen, B.R.; Pérez-Arancibia, N.O. Design and control of a bio-inspired soft wearable robotic device for ankle-foot rehabilitation. *Bioinspir. Biomim.* 2014, 9, 016007.
7. Roy, A.; Krebs, H.; Williams, D. Robot-Aided Neurorehabilitation: A Novel Robot for Ankle Rehabilitation. *IEEE Trans. Neural. Syst. Rehabil. Eng.* 2009, 25, 569–582.
8. Mohammed, S.; Amirat, Y.; Rifai, H. Lower-limb movement assistance through wearable robots: State of the art and challenges. *Adv. Robot.* 2012, 26, 1–22.
9. Senanayake, C.; Senanayake, S.M.N.A. Emerging robotics devices for therapeutic rehabilitation of the lower extremity. In *Proceedings of the 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, Singapore, 14–17 July 2009; pp. 1142–1147.
10. Zhang, L.Q.; Chung, G.; Bai, Z. Intelligent stretching of ankle joints with contracture/spasticity. *IEEE Trans. Neural. Syst. Rehabil. Eng.* 2002, 10, 149–157.
11. Saglia, J.A.; Tsagarakis, N.G.; Dai, J.S. Control strategies for patient-assisted training using the ankle rehabilitation robot (ARBOT). *IEEE/ASME Trans Mechatron.* 2013, 18, 1799–1808.
12. Saglia, J.A.; De Luca, A.; Squeri, V. Design and development of a novel core, balance and lower limb rehabilitation robot: Hunova. In *Proceedings of the 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR)*, Toronto, ON, Canada, 24–28 June 2019; pp. 417–422.
13. Alvarez-Perez, M.G.; Garcia-Murillo, M.A.; Cervantes-Sánchez, J.J. Robot-assisted ankle rehabilitation: A review. *Disabil. Rehabil. Assist. Technol.* 2019, 15, 394–408.
14. Miao, Q.; Zhang, M.; Wang, C. Towards optimal platform-based robot design for ankle rehabilitation: The state of the art and future prospects. *J. Healthc. Eng.* 2018, 2018, 1–9.
15. Boian, R.F.; Deutsch, J.E.; Lee, C.S. Haptic effects for virtual reality-based post-stroke rehabilitation. In *Proceedings of the 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, HAPTICS 2003*, Los Angeles, CA, USA, 22–23 March 2003; pp. 247–253.
16. Deutsch, J.E.; Lewis, J.A.; Burdea, G. Technical and patient performance using a virtual reality-integrated Telerehabilitation system: Preliminary finding. *IEEE Trans. Neural. Syst. Rehabil. Eng.* 2007, 15, 30–35.

17. Boian, R.; Lee, C.; Deutsch, J. Virtual reality-based system for ankle rehabilitation post stroke. In Proceedings of the 1st International Workshop on Virtual Reality Rehabil (Mental Health, Neurological, Physical, Vocational) VRMHR 2002, Lausanne, Switzerland; pp. 77–86. Available online: http://www.ti.rutgers.edu/publications/papers/2002_vrmhr_boian.pdf (accessed on 1 February 2022).
18. Mirelman, A.; Bonato, P.; Deutsch, J.E. Effects of training with a robot-virtual reality system compared with a robot alone on the gait of individuals after stroke. *Stroke* 2008, 40, 169–174.
19. Deutsch, J.E.; Paserchia, C.; Vecchione, C. Improved gait and elevation speed of individuals post-stroke after lower extremity training in virtual environments. *Neurol. Phys. Ther.* 2004, 28, 185–186.
20. Deutsch, J.E.; Latonio, J.; Burdea, G.C. Post-stroke rehabilitation with the Rutgers Ankle system: A case study. *Presence Teleoperators Virtual Environ.* 2001, 10, 416–430.
21. Vallone, F.; Cella, A.; De Luca, A. Effect of a Robotic Training Focused on Balance and Core Stability in Parkinson's Disease: A Pilot Study. 2019. Available online: https://www.movendo.technology/wp-content/uploads/2021/04/Movendo-Clinical-Studies_DEF_web.pdf (accessed on 1 February 2022).
22. Spina, S.; Facciorusso, S.; Cinone, N. Effectiveness of robotic balance training on postural instability in patients with mild parkinson's disease: A pilot, single-blind, randomized controlled trial. *J. Rehabil. Med.* 2021, 53, 2753.
23. Pendolino, L.; Veneziano, G.; Salvato, E. Treatment of Advanced Stage Parkinson Disease with Hunova: A Case Study. 2019. Available online: <https://www.movendo.technology/en/case-studies/treatment-of-advanced-stage-parkinson-disease-with-hunova/> (accessed on 1 February 2022).
24. De Luca, A.; Squeri, V.; Barone, L.M. Dynamic Stability and Trunk Control Improvements Following Robotic Balance and Core Stability Training in Chronic Stroke Survivors: A Pilot Study. *Front. Neurol.* 2020, 11, 494.
25. Marchesi, G.; Ricaldone, E.; De Luca, A. A robot-based assessment of trunk control in Spinal Cord Injured athletes. In Proceedings of the 2020 8th IEEE RAS/EMBS International Conference for Biomedical Robotics and Biomechatronics (BioRob), New York, NY, USA, 29 November–1 December 2020; pp. 497–502.
26. Leo, A.; Bertazzoni, L.; Zarbo, M. The Role of Hunova in Rehabilitative Treatment of Functional Balance in a Patient with Complete Spinal Cord Injury (SCI). 2019. Available online: <https://www.movendo.technology/en/case-studies/the-role-of-hunova-in-rehabilitative-treatment-of-functional-balance-in-a-patient-with-complete-spinal-cord-injury-sci-2/> (accessed on 1 February 2022).
27. Leo, A.; Zarbo, M.; Cassinis, A. The Use of the Robotic Device Hunova as Rehabilitation and Evaluation Tool for Functional Balance in Individuals with Spinal Cord Injury. 12th ISPRM World Congress–ISPRM 2018 (08–12 July 2018, Paris). 2018. Available online: https://www.movendo.technology/wp-content/uploads/2021/04/Movendo-Clinical-Studies_DEF_web.pdf (accessed on 1 February 2022).
28. Cella, A.; De Luca, A.; Squeri, V. Development and validation of a robotic multifactorial fall-risk predictive model: A one-year prospective study in community-dwelling older adults. *PLoS ONE* 2020, 15, e0234904.
29. Bessler, J.; Prange-Lasonder, G.B.; Schulte, R.V.; Schaake, L.; Prinsen, E.C.; Buurke, J.H. Occurrence and Type of Adverse Events during the Use of Stationary Gait Robots-A Systematic Literature Review. *Front. Robot. AI* 2020, 7, 557606.
30. Bessler, J.; Prange-Lasonder, G.B.; Schaake, L.; Saenz, J.F.; Bidard, C.; Fassi, I.; Valori, M.; Lassen, A.B.; Buurke, J.H. Safety Assessment of Rehabilitation Robots: A Review Identifying Safety Skills and Current Knowledge Gaps. *Front. Robot. AI* 2021, 8, 602878.
31. Krebs, H.I.; Palazzolo, J.J.; Dipietro, L.; Ferraro, M.; Krol, J.; Ranekleiv, K.; Volpe, B.T.; Hogan, N. Rehabilitation robotics: Performance-based progressive robot-assisted therapy. *Auton. Robot.* 2003, 15, 7–20.
32. Stefano, M.; Patrizia, P.; Mario, A. Robotic upper limb rehabilitation after acute stroke by NeReBot: Evaluation of treatment costs. *BioMed Res. Int.* 2014, 2014, 265634.
33. Hesse, S.; Heß, A.; Werner, C.C. Effect on arm function and cost of robot-assisted group therapy in subacute patients with stroke and a moderately to severely affected arm: A randomized controlled trial. *Clin. Rehabil.* 2014, 28, 637–647.
34. Wagner, T.H.; Lo, A.C.; Peduzzi, P. An Economic Analysis of Robot-Assisted Therapy for Long-Term Upper-Limb Impairment After Stroke. *N. Engl. J. Med.* 2011, 42, 2630–2632.
35. Stephenson, A.; Stephens, J. An exploration of physiotherapists' experiences of robotic therapy in upper limb rehabilitation within a stroke rehabilitation centre. *Disabil. Rehabil. Assist. Technol.* 2018, 13, 245–252.
36. Li, L.; Tyson, S.; Weightman, A. Professionals' Views and Experiences of Using Rehabilitation Robotics with Stroke Survivors: A Mixed Methods Survey. *Front. Med. Technol.* 2021, 3, 780090.

