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Article

Clinical Demands of Designs for Rehabilitation Robots in Taiwan

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Abstract: Robots have been used in neural rehabilitation. As the development of rehabilitation robots has progressed, the functions and designs of robots become to meet the clinical demands. In Taiwan, the proportion of patients and therapists is high. However, rehabilitation with robots is not widespread in Taiwan. By observing the result of a formative test of a novel rehabilitation robot, the reason for that was investigated. For the investigation, interviews were performed to understand the usability, functions applicability, and ease of use of the robot in rehabilitation. For usability, therapists expected safety for the patient with the robot, and other patients, therapists, and caretakers in the open treatment room. Therapists demanded assisting and training modes, visual and audio feedback, and increasing range of motion of internal and external rotation of shoulder for functions applicability. As for the ease of use, robot operation needs to be simple and fast and give clear standards about the operation for daily operation in treatment rooms. The study result shows humanistic design and glocalization also influence the willingness to use rehabilitation robots except for efficacy-related functions.

Keywords: Demand, Design, Rehabilitation, Robot, Stroke

1. Introduction

Currently, the development of rehabilitation robots has progressed. Robotic rehabilitation has been chosen for neural rehabilitation as the robot automatically provides repetitive training. As passive training mode and gravity compensation function help patients focus on motion control, rehabilitation robots provide early rehabilitation for stroke patients in acute or subacute phases. Combining games or activities of daily living, robots provide functional and task-specific training. The advance in the technique of virtual reality (VR) allows robots to provide simulations close to reality. To provide intensive training for patients, robots usually sense and analyze motions during training, and adjust the difficulty automatically or provide information on the difficulty to therapists. In addition to the information on training difficulty, robots export motion analysis reports and data on the range of motion and kinematic parameters including speed, accuracy, smoothness, and force. Due to the automatic training, rehabilitation robots are expected to reduce the loading of therapists and lower the cost of medical resources. Thus, we review and discuss the features of rehabilitation robots with humanistic design and glocalization to stimulate innovative robotic rehabilitation in the future.

2. Clinical Research and Commercial Rehabilitation Robots

The effect of robotic rehabilitation has been studied widely. Researchers found that robotic rehabilitation is effective in training motor function, activities of daily living, and muscle strength. (Bertani et al., 2017; Chen et al., 2020; Lee et al., 2017; Mehrholz et al., 2018; Wu et al., 2021) Gamification training or training games in robots promote motivation for patients. (Hung et al., 2016; Putrino et al., 2017) Current studies track the changing of kinematic parameters during the stroke recovery process (Goffredo et al., 2019) and research correlations between kinematic parameters and regular clinical scales. Grimm et al. found that there are significant correlations between the Fugl-Meyer assessment for upper extremity (FMA-UE) score and grip force and range of motion of the wrist, elbow, and shoulder. (Grimm et al., 2021)

Overviews of the rehabilitation on the global market are listed in Table 1 which shows that most robots need kinematic parameters. Robots record locations of limbs or hands during training, which are calculated for knowing the speed, acceleration, smoothness, accuracy, and so on. Force parameters are collected by torque sensors within robot joints or by load sensors. After analyzing the kinematic parameters, rehabilitation robots provide active-assist training, gravity compensation, assist-as-need training, and export training reports.

Table 1. Overviews of the rehabilitation robots in the global market.

Product Name	Training Mode	Gravity Compensation	Kinematic Parameters	Force	Interactive Game
Armeo Spring (Allington et al., 2011; Gijbels et al., 2011; Housman et al., 2009; Sanchez et al., 2004; Sanchez et al., 2006; Wolbrecht et al., 2008; Wolbrecht et al., 2006; Zimmerli et al., 2012)	Active Assist (Quantitative assist force for joints by springs. Adjust manually for nine levels.)	Assist force by springs	ROM sencing by potentionmeters.	Force sensor in the handle.	O
Armeo Power (Nef, Guidali, et al., 2009; Nef, Quinter, et al., 2009; Sanchez et al., 2006; Staubli et al., 2009; Zariffa et al., 2012)	Passive Assist (Assist force provided by motors.) Active	Assist force provided by motors	Locations of limbs through time in 3D space.	Interaction force between the robot and the patient by torque sensors.	O
Diego (Meyer-Rachner et al., 2017)	Active	Dynamic gravity compensation by motor through wires	Locations of arms through time in 3D space.	Anti-gravity force of arms.	O
MJS (Iuppariello et al., 2014)	Assist Active	Provide by the motor of the shoulder.	Locations of limbs through time in 3D space.	Force sensor in the handle.	X
Reogo (Bovolenta et al., 2011; Treger et al., 2008)	Guided mode (Passive) Initiated mode Step initiated mode Follow assist mode Free mode (Active)	Weight-bearing on the device	Locations of the endpoint (the hand) through time in 3D space.	Force sensor in the handle.	O
InMotion Arm (Krebs et al., 1998; Krebs et al., 2003; Lo et al., 2010; Masia et al., 2007; Rabadi et al., 2008)	Passive Assist Active	Weight-bearing on the table	Locations of the endpoint (the hand) through time in 2D space.	Force sensor in the handle.	O
Burt (Valdés et al., 2020)	Assist	Weight-bearing on the device	Range of motions		O
ALEx (Pirondini et al., 2014; Ruffaldi et al., 2014)	Passive Assist	Adjustable gravity compensation	Positions and velocities at the end-effector and at each articular joints.	Force sensor in the handle.	O
luna EMG	Passive Assist (EMG) Active Resist	Adjustable gravity compensation	Radius through time	Torque sensors in the motor.	O
Bi-manu track (Hesse et al., 2003)	Passive Assist Active Resist	Weight-bearing on the table	Radius through time	Torque sensors in the motor.	O
Gloreha (Bissolotti et al., 2016; Vanoglio et al., 2017; Villafañe et al., 2018)	Passive Assist Active	Adjustable gravity compensation by twelve levels.	Fingers ROM through time.	X	O

Table 1. *Cont.*

Product Name	Training Mode	Gravity Compensation	Kinematic Parameters	Force	Interactive Game
Cybergrasp (Adamovich et al., 2009)	Passive Assist Active	Gravity compensation by a suspension system.	Fingers ROM through time.	Fingers flexion force and extension force.	O
Hand of hope (Ho et al., 2011)	Assist Active	Weight-bearing on the table	Fingers ROM through time.	X	O
mirror hand	Passive Assist	X	X	X	X
Amadeo (Hwang et al., 2012; Sale et al., 2012)	Passive Assist Active	Weight-bearing on the device	Fingers ROM through time.	Fingers flexion force and extension force.	O
Arm assist (Tomić et al., 2017)	Passive	Weight-bearing on the table	Locations of the endpoint (the hand) through time in 2D space.	Arm support and lifting force.	O
Cybergloves	Active	X	Fingers ROM through time.	X	X
RAPAEL Smart Glove (Jung et al., 2017; Kang et al., 2020; Lee et al., 2019)	Active	X	Wrist and fingers ROM through time.	X	O
HandTutor	Active	X	Wrist and fingers ROM through time.	X	O

Most rehabilitation robots contain multiple training modes. The passive mode helps patients maintain a range of motion or warm-up before training. Various assisting modes detect patients' intentions to lead to completing a motion program for their limbs. The final motion is detected to provide assisting force when the direction shifts from targets. In several modes, robots follow and assist patients' motions. Different assisting modes are available for various patients. When patients have intentions but do not have enough ability to complete motions, robots trigger active-assisted mode to help them. When they perform motions but still need help with motion control, robots help patients with motion direction control in the assisting force mode. When patients have motion control ability but do not have enough muscle strength, robots follow patients' motions to help. Active training mode allows sensing endpoint trajectory and motions of limbs to record and analyze kinematic parameters.

Yet, there is no standard for the training mode of rehabilitation robots. They use different sensors to detect patients' intentions to give various assisting forces, record different parameters, and analyze them in various ways. Experiments for testing the effect of assisting modes require various methods, settings, and sample sizes, and therefore it is hard to compare and discuss the results.

The myoelectrical technique has been applied for a long time. The effectiveness of applications has been studied by using electromyographic (EMG) to detect the electrical signals of muscles with functional electrical stimulation (FES) to trigger movements. Commercial robots such as Hand of hope and Amadeo use EMG for user intention detection. Commercial robots including WalkAide and L300 are commonly used for rehabilitating feet and rarely used on upper limbs. According to the review of Eraifej et al. (2017), using FES within two months of stroke has improved activities of daily living (ADL), and no significant ADL improvement was seen more than one year after stroke. Although more randomized control trials need to be studied due to the low-quality evidence of the result, FES is still a promising therapy for neural rehabilitation. Straudi et al. (2020) showed that combining robot-assisted rehabilitation and FES improved arm impairment but was not effective enough for intensive conventional rehabilitation. The reason is that there were not many robots combining FES with them.

In addition to kinematic parameters detection and myoelectrical application, most rehabilitation robots on the market provide interactive games that provide gamification activities of daily living or commercial games to conform needs of training. Games are a kind of task-oriented training to improve patients' training motivation. In addition to the effect of rehabilitation, robots also are expected to lower the loading of therapists and reduce human costs including fast start, changing sides automatically, giving recommendations of training plans, recording training process designs for device portable, intuitive user interface, and server system for remote controlling multiple devices.

3. Demands for Robots Designs

The proportion of patients and therapists in Taiwan is high, but it is still difficult to provide one-to-one training programs. Usually, patients practice alone or with their families under the supervision of the therapist after a short evaluation. One therapist supervises one to three patients at the same time. Rehabilitation robots are in large demand in this environment. However, robots are not widely used in medical institutions in Taiwan though most robots on the market have functions for satisfying clinical demand.

To understand the reason, thirty-five therapists learned and practiced the operation and used the robot in a simulated situation, and were interviewed after simulations. In the interview, therapists shared their recommendations about the robot. In addition to the recommendations about robot functions, therapists also suggested other features of the robot, which may influence the willingness to use the robot. What most therapists suggested is safety. They expected the safety in using robots for the patient on the rehabilitation robot and other patients, therapists, and caregivers in the open treatment room. Because many of the treatment rooms in Taiwan are open and always crowded during peak hours, the robot needs to be designed to secure safety. They suggested that it is important for robots to have a function of detecting objects in the operating space of the robot, warning and stopping when someone nears it, and avoiding the collision. They also suggested a special battery design to prevent stumbling due to power codes.

Other features may be included such as the ease of use to encourage therapists' willingness to use it. Robots' operating range in space is also a consideration to use in the treatment room. 6.7% of therapists thought that the tested robot is too big for treatment rooms. The operation of robots needs to be simple for fast and easy operation. 50% of therapists suggested using pull bolts instead of knobs to reduce preparing time for the next patient as they have to take care of multiple patients at the same time.

4. Conclusions

The effect of rehabilitation robots has been confirmed as the robot has a significant effect on regular therapy. In this premise, the safety and ease of use of the robots become more important than before. In Taiwan, due to the space limitations of the treatment room, preparing for the next patient needs to be fast since multiple patients are waiting at the same time. Risks in an open treatment room need to be considered not to interrupt other patients, therapists, and caretakers. The study result provides the references for the humanistic design for rehabilitation robots and allows robot design to meet the clinical needs, which promotes the widespread use of rehabilitation robots.

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References

1. Adamovich, S.V., Fluet, G.G., Mathai, A., Qiu, Q., Lewis, J., & Merians, A.S. (2009). Design of a complex virtual reality simulation to train finger motion for persons with hemiparesis: a proof of concept study. *Journal of Neuroengineering and Rehabilitation*, *6*(1), 1–10.
2. Allington, J., Spencer, S.J., Klein, J., Buell, M., Reinkensmeyer, D.J., & Bobrow, J. (2011). Supinator extender (SUE): a pneumatically actuated robot for forearm/wrist rehabilitation after stroke. *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*.
3. Bertani, R., Melegari, C., De Cola, M.C., Bramanti, A., Bramanti, P., & Calabro, R.S. (2017). Effects of robot-assisted upper limb rehabilitation in stroke patients: a systematic review with meta-analysis. *Neurol. Sci.*, *38*(9), 1561–1569. https://doi.org/10.1007/s10072-017-2995-5.
4. Bissolotti, L., Villafañe, J.H., Gaffurini, P., Orizio, C., Valdes, K., & Negrini, S. (2016). Changes in skeletal muscle perfusion and spasticity in patients with poststroke hemiparesis treated by robotic assistance (Gloreha) of the hand. *Journal of Physical Therapy Science*, *28*(3), 769–773.
5. Bovolenta, F., Sale, P., Dall'Armi, V., Clerici, P., & Franceschini, M. (2011). Robot-aided therapy for upper limbs in patients with stroke-related lesions. Brief report of a clinical experience. *Journal of Neuroengineering and Rehabilitation*, *8*(1), 1–6.
6. Chen, Z., Wang, C., Fan, W., Gu, M., Yasin, G., Xiao, S., Huang, J., & Huang, X. (2020). Robot-Assisted Arm Training versus Therapist-Mediated Training after Stroke: A Systematic Review and Meta-Analysis. *J. Healthc. Eng.*, *2020*, 8810867. https://doi.org/10.1155/2020/8810867
7. Eraifej, J., Clark, W., France, B., Desando, S., & Moore, D. (2017). Effectiveness of upper limb functional electrical stimulation after stroke for the improvement of activities of daily living and motor function: a systematic review and meta-analysis. *Systematic Reviews*, *6*(1), 1–21.

8. Gijbels, D., Lamers, I., Kerkhofs, L., Alders, G., Knippenberg, E., & Feys, P. (2011). The Armeo Spring as training tool to improve upper limb functionality in multiple sclerosis: a pilot study. *Journal of Neuroengineering and Rehabilitation*, *8*(1), 1–8.
9. Goffredo, M., Mazzoleni, S., Gison, A., Infarinato, F., Pournajaf, S., Galafate, D., Agosti, M., Posteraro, F., & Franceschini, M. (2019). Kinematic Parameters for Tracking Patient Progress during Upper Limb Robot-Assisted Rehabilitation: An Observational Study on Subacute Stroke Subjects. *Appl. Bionics Biomech.*, *2019*, 4251089. https://doi.org/10.1155/2019/4251089
10. Grimm, F., Kraugmann, J., Naros, G., & Gharabaghi, A. (2021). Clinical validation of kinematic assessments of post-stroke upper limb movements with a multi-joint arm exoskeleton. *J. Neuroeng. Rehabil.*, *18*(1), 92. https://doi.org/10.1186/s12984-021-00875-7
11. Hesse, S., Schulte-Tigges, G., Konrad, M., Bardeleben, A., & Werner, C. (2003). Robot-assisted arm trainer for the passive and active practice of bilateral forearm and wrist movements in hemiparetic subjects. *Archives of Physical Medicine and Rehabilitation*, *84*(6), 915–920.
12. Ho, N., Tong, K., Hu, X., Fung, K., Wei, X., Rong, W., & Susanto, E. (2011). 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*.
13. Housman, S.J., Scott, K.M., & Reinkensmeyer, D.J. (2009). A randomized controlled trial of gravity-supported, computer-enhanced arm exercise for individuals with severe hemiparesis. *Neurorehabilitation and Neural Repair*, *23*(5), 505–514.
14. Hung, Y.-X., Huang, P.-C., Chen, K.-T., & Chu, W.-C. (2016). What do stroke patients look for in game-based rehabilitation: a survey study. *Medicine*, *95*(11).
15. Hwang, C.H., Seong, J.W., & Son, D.-S. (2012). Individual finger synchronized robot-assisted hand rehabilitation in subacute to chronic stroke: a prospective randomized clinical trial of efficacy. *Clinical Rehabilitation*, *26*(8), 696–704.
16. Iuppariello, L., Romano, M., D'Addio, G., Bifulco, P., Pappone, N., & Cesarelli, M. (2014). Comparison of measured and predicted reaching movements with a robotic rehabilitation device. *2014 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*.
17. Jung, H.-T., Kim, H., Jeong, J., Jeon, B., Ryu, T., & Kim, Y. (2017). Feasibility of using the RAPAEL Smart Glove in upper limb physical therapy for patients after stroke: A randomized controlled trial. *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*.
18. Kang, M.-G., Yun, S.J., Lee, S.Y., Oh, B.-M., Lee, H.H., Lee, S.-U., & Seo, H.G. (2020). Effects of Upper-Extremity Rehabilitation Using Smart Glove in Patients With Subacute Stroke: Results of a Prematurely Terminated Multicenter Randomized Controlled Trial. *Frontiers in Neurology*, *11*, 1488.
19. Krebs, H.I., Hogan, N., Aisen, M.L., & Volpe, B.T. (1998). Robot-aided neurorehabilitation. *IEEE Transactions on Rehabilitation Engineering*, *6*(1), 75–87.
20. Krebs, H.I., Palazzolo, J.J., Dipietro, L., Ferraro, M., Krol, J., Rannekleiv, K., Volpe, B.T., & Hogan, N. (2003). Rehabilitation robotics: Performance-based progressive robot-assisted therapy. *Autonomous Robots*, *15*(1), 7–20.
21. Lee, H.-J., Chang, W.H., Lee, A., Kim, H.-G., Ko, S.H., Seong, H.Y., Shin, Y.-I., & Kim, Y.-H. (2019). A Smart Glove Digital System Promotes Restoration of Upper Limb Motor Function and Enhances Cortical Neuroplastic Changes in Subacute Stroke Patients: A Randomized Controlled Trial.
22. Lee, K.W., Kim, S.B., Lee, J.H., Lee, S.J., & Kim, J.W. (2017). Effect of Robot-Assisted Game Training on Upper Extremity Function in Stroke Patients. *Ann. Rehabil. Med.*, *41*(4), 539–546. https://doi.org/10.5535/arm.2017.41.4.539.
23. Lo, A.C., Guarino, P.D., Richards, L.G., Haselkorn, J.K., Wittenberg, G.F., Federman, D.G., Ringer, R.J., Wagner, T.H., Krebs, H.I., & Volpe, B.T. (2010). Robot-assisted therapy for long-term upper-limb impairment after stroke. *New England Journal of Medicine*, *362*(19), 1772–1783.
24. Masia, L., Krebs, H., Cappa, P., & Hogan, N. (2007). Design, characterization, and impedance limits of a hand robot. *2007 IEEE 10th International Conference on Rehabilitation Robotics*.
25. Mehrholz, J., Pohl, M., Platz, T., Kugler, J., & Elsner, B. (2018). Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane Database Syst Rev*, *9*, CD006876. https://doi.org/10.1002/14651858.CD006876.pub5.
26. Meyer-Rachner, P., Passon, A., Klauer, C., & Schauer, T. (2017). Compensating the effects of FES-induced muscle fatigue by rehabilitation robotics during arm weight support. *Current Directions in Biomedical Engineering*, *3*(1), 31–34.
27. Nef, T., Guidali, M., Klamroth-Marganska, V., & Riener, R. (2009). ARMin-exoskeleton robot for stroke rehabilitation. *World Congress on Medical Physics and Biomedical Engineering*, September 7–12, 2009, Munich, Germany.
28. Nef, T., Quinter, G., Müller, R., & Riener, R. (2009). Effects of arm training with the robotic device ARMin I in chronic stroke: three single cases. *Neurodegenerative Diseases*, *6*(5–6), 240–251.
29. Pirondini, E., Coscia, M., Marcheschi, S., Roas, G., Salsedo, F., Frisoli, A., Bergamasco, M., & Micera, S. (2014). Evaluation of a new exoskeleton for upper limb post-stroke neuro-rehabilitation: Preliminary results. In *Replace, Repair, Restore, Relieve–Bridging Clinical and Engineering Solutions in Neurorehabilitation*, pp. 637–645. Springer.

30. Putrino, D., Zanders, H., Hamilton, T., Rykman, A., Lee, P., & Edwards, D.J. (2017). Patient engagement is related to impairment reduction during digital game-based therapy in stroke. *Games for Health Journal*, *6*(5), 295–302.
31. Rabadi, M., Galgano, M., Lynch, D., Akerman, M., Lesser, M., & Volpe, B. (2008). A pilot study of activity-based therapy in the arm motor recovery post stroke: a randomized controlled trial. *Clinical Rehabilitation*, *22*(12), 1071–1082.
32. Ruffaldi, E., Barsotti, M., Leonardis, D., Bassani, G., Frisoli, A., & Bergamasco, M. (2014). Evaluating virtual embodiment with the alex exoskeleton. *International Conference on Human Haptic Sensing and Touch Enabled Computer Applications*.
33. Sale, P., Lombardi, V., & Franceschini, M. (2012). Hand robotics rehabilitation: feasibility and preliminary results of a robotic treatment in patients with hemiparesis. *Stroke Research and Treatment*, *2012*.
34. Sanchez, R., Reinkensmeyer, D., Shah, P., Liu, J., Rao, S., Smith, R., Cramer, S., Rahman, T., & Bobrow, J. (2004). Monitoring functional arm movement for home-based therapy after stroke. *The 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*.
35. Sanchez, R.J., Liu, J., Rao, S., Shah, P., Smith, R., Rahman, T., Cramer, S.C., Bobrow, J.E., & Reinkensmeyer, D.J. (2006). Automating arm movement training following severe stroke: functional exercises with quantitative feedback in a gravity-reduced environment. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *14*(3), 378–389.
36. Staubli, P., Nef, T., Klamroth-Marganska, V., & Riener, R. (2009). Effects of intensive arm training with the rehabilitation robot ARMin II in chronic stroke patients: four single-cases. *Journal of Neuroengineering and Rehabilitation*, *6*(1), 1–10.
37. Straudi, S., Baroni, A., Mele, S., Craighero, L., Manfredini, F., Lamberti, N., Maietti, E., & Basaglia, N. (2020). Effects of a robot-assisted arm training plus hand functional electrical stimulation on recovery after stroke: a randomized clinical trial. *Archives of Physical Medicine and Rehabilitation*, *101*(2), 309–316.
38. Tomić, T.J.D., Savić, A.M., Vidaković, A.S., Rodić, S.Z., Isaković, M.S., Rodríguez-de-Pablo, C., Keller, T., & Konstantinović, L.M. (2017). ArmAssist robotic system versus matched conventional therapy for poststroke upper limb rehabilitation: a randomized clinical trial. *BioMed Research International*, *2017*.
39. Treger, I., Faran, S., & Ring, H. (2008). Robot-assisted therapy for neuromuscular training of sub-acute stroke patients. A feasibility study. *European Journal of Physical and Rehabilitation Medicine*, *44*(4), 431–435.
40. Valdés, B.A., Khoshnam, M., Neva, J.L., & Menon, C. (2020). Robotics-assisted visual-motor training influences arm position sense in three-dimensional space. *Journal of Neuroengineering and Rehabilitation*, *17*(1), 1–11.
41. Vanoglio, F., Bernocchi, P., Mulè, C., Garofali, F., Mora, C., Taveggia, G., Scalvini, S., & Luisa, A. (2017). Feasibility and efficacy of a robotic device for hand rehabilitation in hemiplegic stroke patients: a randomized pilot controlled study. *Clinical Rehabilitation*, *31*(3), 351–360.
42. Villafañe, J.H., Taveggia, G., Galeri, S., Bissolotti, L., Mullè, C., Imperio, G., Valdes, K., Borboni, A., & Negrini, S. (2018). Efficacy of short-term robot-assisted rehabilitation in patients with hand paralysis after stroke: a randomized clinical trial. *Hand*, *13*(1), 95–102.
43. Wolbrecht, E.T., Chan, V., Reinkensmeyer, D.J., & Bobrow, J.E. (2008). Optimizing compliant, model-based robotic assistance to promote neurorehabilitation. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *16*(3), 286–297.
44. Wolbrecht, E.T., Leavitt, J., Reinkensmeyer, D.J., & Bobrow, J.E. (2006). Control of a pneumatic orthosis for upper extremity stroke rehabilitation. *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*.
45. Wu, J., Cheng, H., Zhang, J., Yang, S., & Cai, S. (2021). Robot-Assisted Therapy for Upper Extremity Motor Impairment After Stroke: A Systematic Review and Meta-Analysis. *Phys. Ther.*, *101*(4). https://doi.org/10.1093/ptj/pzab010.
46. Zariffa, J., Kapadia, N., Kramer, J., Taylor, P., Alizadeh-Meghrazi, M., Zivanovic, V., Willms, R., Townson, A., Curt, A., & Popovic, M. (2012). Feasibility and efficacy of upper limb robotic rehabilitation in a subacute cervical spinal cord injury population. *Spinal. Cord.*, *50*(3), 220–226.
47. Zimmerli, L., Krewer, C., Gassert, R., Müller, F., Riener, R., & Lünenburger, L. (2012). Validation of a mechanism to balance exercise difficulty in robot-assisted upper-extremity rehabilitation after stroke. *Journal of Neuroengineering and Rehabilitation*, *9*(1), 1–13.

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