2019 CMBEC42
Ottawa, ON
CMBES/SCGB May 21-24, 2019

Novel Concept of a Lower-limb Rehabilitation Robot Targeting Bed-bound Acute Stroke Patients

N. J. Berezny[1], D. Dowlatshahi[2] and M. Ahmadi[1]

[1] Carleton University - Mechanical and Aerospace Engineering, Ottawa, Canada
[2] University of Ottawa & Ottawa Hospital Research Institute, Ottawa, Canada

Abstract— **A novel concept for a stroke rehabilitation robot is presented, which incorporates ideas gathered after conducting fieldwork at a local hospital with five therapists. Data collected from the hospital and from recent stroke rehabilitation guidelines revealed key insights which generated ideas for a new device based in part upon our previous robot, the Virtual Gait Rehabilitation Robot (ViGRR). The new concept differs from existing rehabilitation robots in that it can be used independent of the therapist, who often have very limited schedules. Other issues are addressed, such as combating a lack of motivation or attention found in some patients. Future trials are discussed, including clinical trials measuring functional outcomes as well as less common metrics such as user engagement.**

Keywords— **Robotics, Rehabilitation, Acute Stroke, Therapy, Virtual Environment**

I. INTRODUCTION

The field of stroke rehabilitation robotics has been around for several decades now, with devices developed for a myriad of exercises and motions. Their prevalence is likely due to the increasing volume of strokes (62,000 a year in Canada as of 2015 [1]) and consequently the necessity for novel ways of applying rehabilitation more broadly and efficiently. Researchers have proposed a number of potential benefits associated with the use rehabilitation robots, including benefits to the therapist (e.g relieving the burden of physical therapy [2]), to the patient (e.g. increasing therapy duration and intensity, & by making therapy more engaging [3]), and to the effective administration of rehabilitation (e.g. by providing quantitative performance measures [4]).

Rehabilitation robotics are usually categorized as targeting the upper- or lower-limbs, and as either exoskeleton-based or end-plate based. Exoskeletal robots offer greater control over motion by attaching at multiple points along the limb, but can also be more complex and expensive [5]. End-plate devices interface with the user at one point, simplifying the structure and controller. Devices targeting the lower-limb can be further categorized as out-of-bed or bed-bound. Much of the literature focuses on out-of-bed devices which are typically used to assist the patient through gait trajectories, often in conjunction with bodyweight supported treadmill training. One of the most cited lower-limb devices is the Lokomat [6], which has been found in one study to be more effective than conventional gait therapy with regards to certain outcome measures [7]. However, many studies have found conflicting results – one notable review concluded that traditional therapy was more effective [8]. Devices designed for bed-bound, acute stroke patients are scarcer [9]. Some examples include the Rutger's Ankle [10], a 4-DOF Wire Driven System [11], Physiotherabot [12], and NeXOS [13].

The importance of active engagement during therapy has been emphasized recently in the literature, as passive-motion has been found to be ineffective [14]. The need for active participation has been attributed to it's fundamental role in neural plasticity, the process by which the brain forms new nueral connections and thus learns new tasks [15]. While engagement is quickly becoming a requirement of rehabilitation robotics, the methods for ensuring it vary. Some researchers have developed robot controllers which can increase user engagement by modulating human-robot interaction dynamics. For example, adaptive controllers can increase the difficulty of the exercise to continually challenge the user, or EMG-based controllers can respond only when an intent to move is detected [16]. Virtual reality (VR) and haptic feedback have also been used to engage patients, and to increase the relevancy of the exercise by simulating real-life activities. In a review on the use of VR for rehabilitation (both upper and lower-limb), meta-analysis found evidence that VR improves outcomes, however the literature lacked large studies or comparisons of types of VR [17].

The Virtual Gait Rehabilitation Robot (ViGRR), designed by the authors, is an end-plate based device targeting bed-bound acute stroke patients [18, 19]. It consists of a four degree-of-freedom robotic leg capable of assisting users through gait trajectories in the sagittal plane, and also incorporates VR and haptic feedback. The device has been used to validate an interaction controller which can provide assistance or resistance to the user. To establish ViGGR (or other similar lower-limb devices targeting acute stroke patients) as a valuable part of the lower-limb stroke rehabilitation reg-

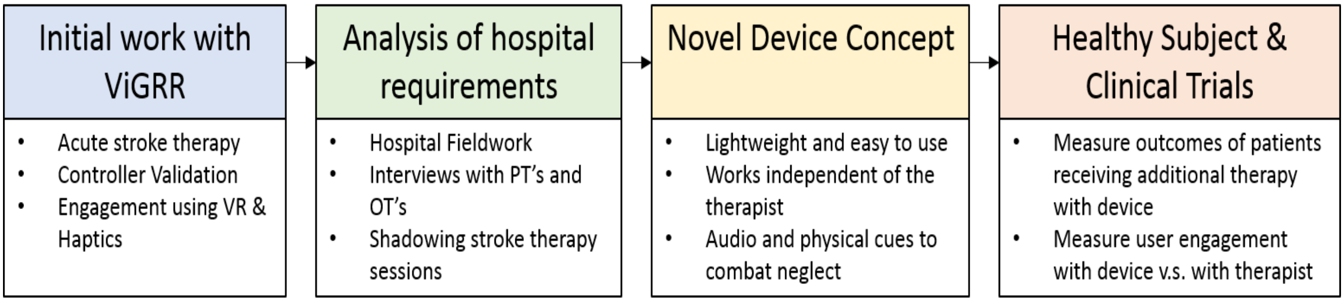

Fig. 1: The Design Process

imen, clinical trials are required. However, ViGGR is not amenable to the hospital environment, due to it's large size and it's high-powered hardware. Therefore, it was decided that another design iteration would be undertaken in order to build a lighter-weight version suitable for clinical trials at a hospital. This next iteration would contain the fundamentals of ViGRR, such as being a lower-limb endplate-based robot targeting bed-bound stroke patients, and the incorporation of VR and haptic feedback as means to increase user engagement. The design process for this new iterations can be found in Fig. 1.

II. Fieldwork

While the literature provides a good overview for the technical criteria of the device, the thoughts and ideas of the end-user are not as well-represented [14]. The therapists and doctors staffed at the stroke ward are ultimately in charge of the patient's rehabilitation routine, and consequently the success of the device is contingent on them finding the robot beneficial. To learn more about stroke rehabilitation, and get input from hospital staff with stroke rehabilitation experience, the authors conducted fieldwork at a local hospital, with ethics approval from the Ottawa Health Science Network Research Ethics Board (OHSN-REB).

Three physiotherapists (PT's) and two occupational therapists (OT's) were recruited for two days of interviews and shadowing. Inclusion criteria included experience working on the stroke ward performing rehabilitation with acute stroke patients. The PT's typically focused on gross motor movement, coordination, and gait; the OT's focused more on fine motor skills and activities of daily living like eating and dressing. Shadowing entailed following and observing as the therapist worked with patients through whatever rehabilitation activity was planned for that day. Additionally, informal interviews were conducted with the therapists both individually and in a group setting. Not enough data was collected to perform any meaningful statistics, however qualitative analysis allowed for a few key insights to be discerned. Topics of interest included typical bed-bound therapy activities, approximate therapy dosage for lower-limb rehabilitation, and methods used by therapists to engage patients.

Most bed-bound exercises were simple, usually involving a single type of movement. The most common were leg lifts, knee flexion/extension, hip abduction or rotation, and ankle dorsiflexion. Therapists provided assistance to some patients, especially those who had recently suffered stroke. More advanced patients did the exercises on their own, or with light resistance applied by the therapist. While these exercises are important, more time was spent on out-of-bed activities. Typically, the goal is to get the patient standing as soon as possible so they can begin to recover gait [1]. Out-of-bed rehabilitation included practising sit-to-stand movements, walking with assistance and stair climbing.

Therapists generally have a high workload and so must carefully schedule time with patients. At this particular hospital, patients got on average 30 minutes every other day with a physiotherapist for lower-limb rehabilitation. Most patients were fatigued by the end of the session, and so increasing the duration is not reasonable. However, the therapists recognized that the patients could benefit from more sessions throughout the week. This is is in line with a study investigating therapy dosage, which found that some patients may not be receiving enough motion repetitions during in-patient therapy [20]. While these results are not conclusive (required therapy dosage was approximated using animal models), they do support the idea that patients could gain from receiving practice beyond that which is currently provided by therapists.

An important note observed and stated explicitly by some of the physiotherapists is the need for encouragement and stimulation to keep the patient's attention. This parallels the emphasis on active engagement found in the literature review. However, while robotics researchers focus more on either engaging patients by challenging them or through virtual environments, therapists were instead focused on a more fundamental kind of engagement. Many stroke victims suffer from hemispatial neglect, or a lack of attention to the affected side of the body. Consequently, the therapist often has to "remind" the patient of the task at hand, through speaking (either casual conversation or firm motivation, similar to a physical trainer), tapping the targeted limb, or by other tactile or physical means. Based on the literature review, many rehabilitation robots do not address the need to overcome neglect, or rely on a therapist to be present to do so.

III. Novel Device Concept

The data collected from the hospital and from the literature yielded key insights which have generated a new concept for the device. Both the literature and information gathered from the hospital indicate that patients could benefit from additional therapy, beyond what is allotted to traditional therapy. This is in agreement with stroke guidelines, which recognize the potential benefits of letting patients practice rehabilitation movements learned from the therapist on their own [1]. Independent practice is possible for more advanced patients, however bed-bound patients or those who have suffered more severe strokes may not have enough strength or coordination to practice without assistance. Patients may also lack the motivation or attention to practice on their own time, due in part to hemispatial neglect. Therefore there is a need for a device that could assist and engage patients in additional bed-bound rehabilitation.

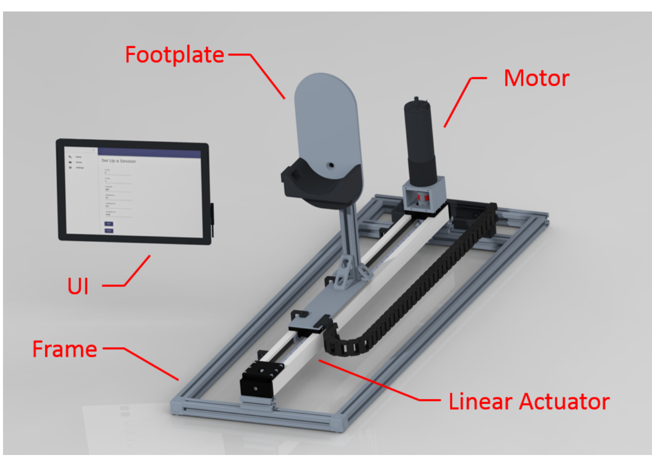

Fig. 2: Rehabilitation Robot and User Interface

Under this criteria, the first prototype was designed and built (Fig. 2) as a simple one degree-of-freedom device which sits on the bed underneath the patient's leg. To keep initial testing simple, the device only targets the knee flexion-extension exercise (Fig. 3). Preparing the device for use does not require in-depth knowledge of the robot or of stroke rehabilitation – one only has to place the patient's foot into the footrest, adjust hard limits to ensure the device does not over-extend the leg, and then set up a session through the device's user interface (UI). The UI allows for the adjustment of parameters to accommodate a variety of patients, and for switching between assistive and resistive modes. Once started, the robot will assist the patient through a knee flexion/extension exercise by applying small corrective forces to the foot whenever they deviate from a desired trajectory. The UI is also used to display feedback to the patient, including their current position within the motion and the desired position. Virtual games which work with haptic feedback to engage the patient are also displayed through the UI. Furthermore, to combat neglect, features will be included and tested which mimic the methods of traditional therapy, including voice instructions, or tactile reminders delivered to the leg.

This device targets only a single exercise, which is a clear disadvantage. Upon proof-of-concept with the prototype, future design iterations will add degrees of freedom so that other bed-bound exercises can be utilized. Ideally, this device would perform all the standard bed-bound exercises listed in Sec. II., and will likely be more similar to ViGRR in its configuration.

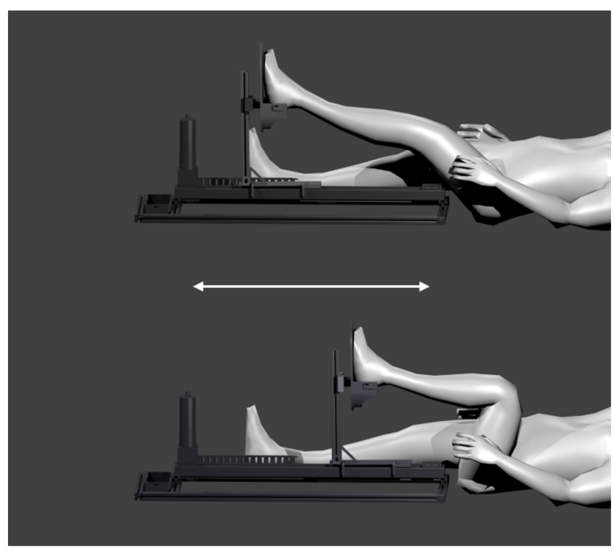
Fig. 3: Knee Flexion/Extension with the Robot

IV. Conclusion & Future Experiments

Future experiments will measure performance and functional outcomes on both healthy subjects and acute stroke patients. These experiments will differ from the majority of other research in that user engagement will be a primary metric, which can be measured via subjective questionnaire, observation, and certain biometrics. Engagement can be compared between users of the robot, versus a control of either patient's who practice on their own or those assisted by a therapist. It is predicted that the device will yield increased engagement, or at least equal engagement to patients working with a therapist.

In conclusion, information from the literature and gathered from fieldwork at a local hospital has generated a novel concept for a lower-limb rehabilitation robot. The device can assist patients in performing simple exercises in bed, based on exercises used by physiotherapists. The device does not require a therapist to operate, so that it can be used to provide additional therapy as suggested by stroke rehabilitation guidelines. The device assists the patient in two distinct ways: by assisting in the actual motion of the leg, and by using VR, haptic feedback, and other means to engage the patient.

Conflict of Interest

The authors declare that they have no conflict of interest

References

1. Hebert Debbie, Lindsay M Patrice, McIntyre Amanda, et al. Canadian stroke best practice recommendations: Stroke rehabilitation practice guidelines, update 2015 *International Journal of Stroke.* 2016;11:459–484.
2. Colombo G, Wirz M, Dietz V. Driven gait orthosis for improvement of locomotor training in paraplegic patients *Spinal Cord.* 2001;39:252–255.
3. Calabrò Rocco Salvatore, Cacciola Alberto, Bertè Francesco, et al. Robotic gait rehabilitation and substitution devices in neurological disorders: where are we now? *Neurological Sciences.* 2016;37:503–514.
4. Díaz Iñaki, Gil Jorge Juan, Sánchez Emilio. Lower-Limb Robotic Rehabilitation: Literature Review and Challenges *Journal of Robotics.* 2011;2011:1–11.
5. Chang Won Hyuk, Kim Yun-Hee. Robot-assisted Therapy in Stroke Rehabilitation. *Journal of stroke.* 2013;15:174–81.
6. Jezernik Sašo, Colombo Gery, Keller Thierry, Frueh Hansruedi, Morari Manfred. Robotic Orthosis Lokomat: A Rehabilitation and Research Tool *Neuromodulation: Technology at the Neural Interface.* 2003;6:108–115.
7. Nam Ki Yeun, Kim Hyun Jung, Kwon Bum Sun, Park Jin-Woo, Lee Ho Jun, Yoo Aeri. Robot-assisted gait training (Lokomat) improves walking function and activity in people with spinal cord injury: a systematic review *Journal of NeuroEngineering and Rehabilitation.* 2017;14:24.
8. Hidler J., Nichols D., Pelliccio M., et al. Multicenter Randomized Clinical Trial Evaluating the Effectiveness of the Lokomat in Subacute Stroke *Neurorehabilitation and Neural Repair.* 2008;23:5–13.
9. Mehrholz J, Pohl M. Electromechanical-assisted gait training after stroke: A systematic review comparing end-effector and exoskeleton devices *Journal of Rehabilitation Medicine.* 2012;44:193–199.
10. Girone M., Burdea G., Bouzit M., Popescu V., Deutsch J.E.. A Stewart Platform-Based System for Ankle Telerehabilitation *Autonomous Robots.* 2001;10:203–212.
11. Homma K., Fukuda O., Sugawara J., Nagata Y., Usuba M.. A wire-driven leg rehabilitation system: development of a 4-DOF experimental system in *Proceedings 2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2003)*;2:908–913IEEE.
12. Akdoğan Erhan, Adli Mehmet Arif. The design and control of a therapeutic exercise robot for lower limb rehabilitation: Physiotherabot *Mechatronics.* 2011;21:509–522.
13. Bradley D., Acosta-Marquez C., Hawley M., Brownsell S., Enderby P., Mawson S.. NeXOS – The design, development and evaluation of a rehabilitation system for the lower limbs *Mechatronics.* 2009;19:247–257.
14. Krebs Hermano, Volpe Bruce, Hogan Neville. A working model of stroke recovery from rehabilitation robotics practitioners *Journal of NeuroEngineering and Rehabilitation.* 2009;6:6.
15. Warraich Zuha, Kleim Jeffrey A.. Neural Plasticity: The Biological Substrate For Neurorehabilitation *PM&R.* 2010;2:S208–S219.
16. Meng Wei, Liu Quan, Zhou Zude, Ai Qingsong, Sheng Bo, Xie Shengquan (Shane). Recent development of mechanisms and control strategies for robot-assisted lower limb rehabilitation *Mechatronics.* 2015;31:132–145.
17. Laver K, George S, Thomas S, Deutsch J E, Crotty M. Virtual reality for stroke rehabilitation: an abridged version of a Cochrane review. *European journal of physical and rehabilitation medicine.* 2015;51:497–506.
18. Chisholm K. J., Klumper K., Mullins A., Ahmadi M.. A task oriented haptic gait rehabilitation robot *Mechatronics.* 2014;24:1083–1091.
19. Chisholm Kyle, Klumper Kyle, Ahmadi Mojtaba. Lower-Extremety Gait Rehabilitation Robotic System 2014:1–6.
20. Lang Catherine E., MacDonald Jillian R., Reisman Darcy S., et al. Observation of Amounts of Movement Practice Provided During Stroke Rehabilitation *Archives of Physical Medicine and Rehabilitation.* 2009;90:1692–1698.